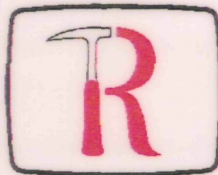


**INTERIM REPORT: QUESTA WASTE ROCK PILE DRILLING,  
INSTRUMENTATION AND CHARACTERIZATION STUDY**



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**September 13, 1999**

Report No. 052007/1

Robertson GeoConsultants Inc.  
September 13, 1999

## Executive Summary

This interim report describes the nature of, and early results from, geochemical characterization, investigation drilling and drill hole instrumentation for four mine waste rock piles at the Questa mine, New Mexico. The investigations were made in partial satisfaction of Tasks 1.3, 1.4 and 1.5 of the first phase of a waste pile geotechnical and geochemical characterization program that was committed to by MolyCorp, Inc. in a submittal to NMED dated July 31, 1998.

The investigation comprised drilling of 9 holes using a top hammer driven double walled casing (6" ID, 9" OD) to depths of between 60 and 125 ft. in the Spring, Sugar Shack South and West and Capulin waste rock piles. The drill rig was selected to allow representative sampling of up to 6" diameter waste particles, minimizing crushing and size reduction during drilling. Drill holes were generally located near the base, at mid height and top of piles to investigate the geotechnical and geochemical conditions at all levels within the piles. Holes were drilled until they just penetrated foundation soils or bedrock. Samples were collected, each representing 5 ft of advance. The holes were instrumented by installing thermistors (to measure temperature), pore gas sampling tubes (to measure oxygen and carbon dioxide content) and with a perforated casing to allow water sampling (if encountered) at the pile base/foundation soil contact.

One set of temperature measurements has been made but, as yet, no gas sampling has been performed. The samples were subjected to laboratory tests to determine paste pH (indicating the current acidity condition of the waste, and the location of the acid fronts in the piles), paste conductivity (indicating the quantity of soluble salts in the waste, and the potential contaminant load in leach waters) and moisture content (indicating the moisture content of the waste and hence providing an indication of the drying effects in various zones in the pile). Additional testing (both static and kinetic ARD tests) is still to be completed to fully characterize the nature and likely kinetic future behavior of the wastes. The testing completed to date provides an indication of current conditions.

At this time this information can be used to draw initial conclusions relating to four questions of interest:

### **1. What are the geotechnical and geochemical characteristics of the waste at depth in the piles?**

The geotechnical characteristics of the waste piles are such that there is typically segregation down the dumped slopes resulting in a boulder layer (coarse waste with high air permeability) at the base of the piles and a zone with greater fines near the upper dumping platform. The coarse base layer serves as both a high permeability flow channel for air and as a suction break layer between the foundation soils and the finer grained wastes higher in the pile.

The current acidic condition of the piles is defined by the paste pH of the samples. One drill hole profile (WRD-1 in lower Spring pile), in aplite rock waste, is entirely neutral (and acid consuming). Three of the drill holes (WRD-5 in Sugar Shack South pile, WRD-6 and 7 in Sugar Shack West pile) have substantial acidic zones of mixed volcanics at the top of the piles but the lower zones are neutral and acid consuming. Two of the drill

holes (WRD-3 and 4 in Sugar Shack South pile) have some depressed pH zones but are neutral or acid consuming at the base. Three of the drill holes (WRD-2 in upper Spring pile and WRD-8 and 9 in Capulin pile) are primarily in mixed volcanics and tuffs and acidic for their entire depths.

The temperature profiles indicate no temperature rise in the drill hole that has no acid generation. All other holes show some increase in temperature with the greatest increases in temperature being observed in holes higher up the pile slope, and at the base of the pile at each drill hole location. This clearly indicates rising heat in the air permeable coarse base zone.

The moisture conditions in the piles indicate fairly dry conditions near the base of most piles with all foundation drilling yielding dusty cuttings. No water was encountered at the pile/foundation soil or bedrock interface. The moisture content was higher in the piles at higher elevations, and increased at higher elevations in the same pile.

The downward percolation in partially saturated piles occurs mainly as a slow downward migration of the pore fluids in response to pore tension release (by infiltration) at the surface. Discrete channel flow in such 'dry' piles is expected to occur only near the surface. The acidic condition at the base of the pile defines the potential for acidic drainage from the base of the pile. If the base of the pile is alkaline then any downward percolating acidic drainage will be neutralized before exiting the pile. The pH of the wastes near the base of the pile therefore determines the pH of drainage from the pile. Two conditions must occur for acidic drainage from the base of the pile:

1. The pH in the seepage path at the base of the pile must be acidic, and
2. There must be active downward migration of the acidic fluid (transport mechanism).

## **2. What are the acidic conditions near the base of the piles investigated?**

From the paste pH profiles it is apparent that the base of the piles are acidic only at the locations of WRD-2 in upper Spring pile, WRD-8 and 9 in Capulin pile.

## **3. Does a transport mechanism exist in the piles investigated?**

The temperature profiles and low moisture content near the base of the piles appears to indicate that there is a substantial drying effect occurring as a result of air movement through the piles. WRD-8 in Capulin pile is the only drill hole profile which does not show marked drying towards the base. This hole also has the highest average moisture content. Capulin pile is the only pile from which toe seepage is observed. This seepage yield may be the result of seepage from the pile as a consequence of: (a) the high elevation of the pile itself, which experiences higher precipitation and infiltration; (b) a lower evaporation rate resulting from the generally finer grained (less air permeable) waste in this pile. It could also be substantially due to natural springs discharging below the pile. Such springs are observed at the same elevation as the pile, emerging adjacent to the pile and also emerging into the pit on the opposite side of the ridge from the pile.

Based on the preliminary information available from this study, it is our opinion that pile zoning and air movement through the piles is having a substantial effect on the potential

for leaching from the piles and should be investigated further in order to optimize reclamation measures.

**4. What are the issues of concern relating to resloping of the Questa waste piles?**

The topography on which the majority of the piles have been placed at Questa is steep, resulting in many of the piles being very high but with a shallow depth of waste rock. This geometry increases the potential for 'chimney' effects in the piles, which increases the potential for air-drying within the piles. It also makes it difficult, and sometimes technically infeasible, to reslope the piles.

In addition to concerns regarding the space available for resloping there are two issues that are apparent as a result of the present geotechnical and geochemical investigation. The first is that the conventional (practical and economic) method of resloping a pile, by pushing material down from the top, would generally result in acid generating fine mixed volcanic waste being pushed down from the upper pile benches over the non acid generating (acid consuming) coarse aplite waste of the lower wrap around benches. This action would increase the potential for acidic surface water run-off and infiltration. Secondly, the pushing down of fine waste to cover the coarse waste will reduce the air flow through the piles and hence decrease the drying effects and increase the potential for acidic drainage through the base of the piles.

In order to propose the most effective reclamation measures, it is necessary to first complete the characterization studies currently underway and proposed by Molycorp in their July 31, 1998, submission to NMED. The implementation of resloping or relocation measures without a clear understanding of the geochemical characteristics and properties of piles could result in adverse consequences.

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## INTERIM REPORT: QUESTA WASTE ROCK PILE DRILLING, INSTRUMENTATION AND CHARACTERIZATION STUDY

### 1.0 INTRODUCTION AND TERMS OF REFERENCE

#### 1.1 Location

The Questa molybdenum mine is located approximately 5 miles east of the town of Questa in Taos County in north central New Mexico. The mine property lies within the range of the Sangre de Cristo mountains and is bounded on the south by the Red River and on the north by the Cabresto Creek drainage. The property location and main mine facilities are illustrated in Figure 1.

#### 1.2 Previous Geochemical Characterization Studies

The focus of this study is on a preliminary investigation of the acid generating characteristics and the current state of acid rock drainage (ARD) from the waste rock piles that were developed during open pit mining performed between 1964 and 1984. This mining resulted in the placement of 328 million tons of waste rock in 9 waste rock piles at the locations shown on Figure 1. The steep mountainous terrain results in unusually high piles with relatively shallow deposits.

The waste rock contains sulfides in differing concentrations and some of the waste rock is acid generating. A preliminary characterization of the waste rock was made in 1995 and is reported in:

**"Questa Molybdenum Mine: Geochemical Assessment"**, prepared by Steffen, Robertson and Kirsten (USA) Inc., dated April 13, 1995. (SRK, 1995)

That report provides a detailed description of the site topography, climate, geology and geochemistry and should be read in conjunction with this report. This earlier study involved only surface sampling and geochemical characterization. It made recommendations for further investigations to adequately characterize the Questa waste rock piles.

A second more extensive surface geochemical and geotechnical characterization study was performed in late 1995 and the results are provided in:

**"Surface Characterization Plan"**, prepared by Steffen, Robertson and Kirsten, 1996. (SRK, 1996). This surface characterization has been incorporated into the Section 4 of **"Revegetation Report for MolyCorp, Inc."** by A.M. Wagner and J.T. Harrington, dated December, 29, 1995. (Wagner & Harrington, 1995).

The results of that surface geochemical characterization should be read in conjunction with this report.

In its submittals to NMED in July 31, 1998, Molycorp undertook to perform additional geochemical and geotechnical investigations in accordance with the SRK recommendations. NMED has reviewed these proposed studies and concurred subject to public comments and further assessment. A description of the objectives of this additional geotechnical and geochemical characterization study is provided in Molycorp's submittal:

**"Questa Mine Waste Rock Discharge Plan DP-1055"** to NMED dated July 31, 1998. (Molycorp, 1998)

This submittal provides a detailed description of the proposed five-year characterization and monitoring program. The program is divided into two phases with a number of tasks in each phase.

### 1.3 Objectives of This Study

This interim report provides a description of the results achieved to date for Tasks 1.3, 1.4 and part of subtask i) of Task 1.5 of this program.

In order for Molycorp to develop appropriate ARD control measures it is necessary to understand:

1. The potential for ARD
2. The kinetics of acid generation of the waste rock types (rates of oxidation and its change with time)
3. The kinetics of leaching of the waste rock types (nature and solubility of contaminants produced during oxidation)
4. The oxygen flux through the rock piles (how much and where oxygen penetrates into the piles)
5. The rates of infiltration (hence the rates of leaching and acid flux driving the migration of the acid front)
6. The neutralization potential in the anoxic zones in the pile (to determine the rate of migration of the acid front)

There are a number of site specific conditions at Questa which are unusual (with respect to the development of ARD control measures) which make it necessary to clearly understand the kinetics of ARD in the piles for designing and applying ARD control measures. These are:

1. The steep mountainous terrain results in unusually high piles. The waste rock piles extend between elevations 7,900 and 9,900 ft elevation (2,000 ft elevation difference) resulting in piles with high vertical relief but relatively shallow waste rock deposits.
2. The toe constraint imposed by valley bottoms (and their associated creeks), particularly the Red River and adjacent national road, makes the resloping of most of

the waste rock piles impractical. ARD control measures must therefore be applied to steep pile faces. These spatial restrictions severely limit the nature of the controls that can be implemented and compels careful examination of the potential benefits of those measures that are practical (such as minimization of infiltration by sustainable measures such as revegetation).

3. The air flux through the pile, particularly thermal convective flux, will be high because of the high relief and the thermal contrast (temperature in the pile compared with ambient winter and summer temperatures). High air flux implies high oxygen flux as air flows into the pile through coarse rock at the base of the piles and exits through 'chimneys' in the heterogeneous piles. This effect may introduce large quantities of oxygen at the base of the piles, increasing the oxidation in this location. The entry of cold dry air in the winter (or whenever the ambient air temperature is below that of the interior of the waste rock piles), and its exhaust as a warmer moister air, will remove water from the pile. This air movement is expected to have a significant effect on the water balance in the piles and therefore for the potential for seepage from the base of the piles.
4. The high relief contrast results in a large variation in the precipitation on the piles dependent on the elevation, with the highest elevations getting almost twice the precipitation of the lower elevations. The kinetics of infiltration (hence potential seepage) differs for portions of piles at high elevations compared with those at lower elevations. The effectiveness of infiltration limiting measures in protecting groundwater will therefore differ depending on the elevation of the pile under consideration.

The waste rock characterization program was designed to develop an understanding of the overall pile static and kinetic characteristics. It was proposed that this be done using a staged approach. In Phase 1, three of the piles would be investigated, instrumented and monitored to determine:

1. static and kinetic characteristics of the waste rock located in that pile:
2. the current location of the oxidation, acid and contaminant fronts within the piles at the investigative borehole locations; and
3. the temporal (over time) variation of temperature, oxygen and moisture content in the profiles of the investigative boreholes.

The results of the investigation and monitoring would be used to generate and calibrate models of these three piles allowing their future kinetic performance to be evaluated, with and without alternative control measures. Phase 1 would take 3 years to complete.

In Phase 2, the results of Phase 1 would be used to plan and implement an investigative program which will allow the remaining piles to be characterized, modeled and closure measures to be designed and verified. Phase 2 would be optimized to investigate the critical characterization parameters identified during Phase 1 and fill any data gaps determined from the earlier program.

Tasks 1.3 and 1.4 of the characterization and monitoring program provides for the drilling of 9 boreholes in three piles and a scar area in order to obtain samples for

geotechnical and geochemical characterization and to enable instruments to be installed in the boreholes to determine the conditions of temperature, oxygen and carbon dioxide content, and moisture profiles in order to adequately characterize these piles. Subtask 1.5 i) provides for sample descriptions and characterization testing (grading, moisture content, paste pH and conductivity).

## 2.0 DRILLING AND INSTRUMENTATION

### 2.1 Task 1.3 Phase 1 Drilling and Sampling Program

Task 1.3 has been completed essentially in accordance with the activities and methods proposed in Molycorp, 1998, as reviewed by NMED. Nine drill holes were drilled in four waste piles at the locations shown on Figures 2, 3 and 4. Seven of the drill holes were located in the three piles originally proposed for the following reasons:

**Sugar Shack West Pile.** This high pile appears to be comprised primarily of andesite waste rock with a high acid generating potential. It is located over foundation bedrock that is not scar material. It was proposed that two exploration and instrumentation boreholes be installed in this pile. One is at the top near the rear of the pile to investigate the oldest waste (first placed) and kinetic conditions at the back and rear of the pile. The other is near the toe to investigate the youngest waste (last placed) and kinetic conditions near the toe of the pile.

**Sugar Shack South Pile.** This high pile represents a mixed material pile with primarily acid generating andesites in the higher portions of the pile and predominantly acid consuming aplite in the lower portions of the pile. It is located over an area of 'scar' foundation rock. It was proposed that three exploratory and instrumented boreholes be drilled in this pile. Holes were located near the back and near the toe of the pile for the reasons described for Sugar Shack West. The third borehole was located at approximately mid height on the pile to investigate materials and conditions at this location of this more complex pile.

**Spring Gulch Pile.** This is a lower pile comprised mainly of aplite waste rock and located over non-scar bedrock. As for Sugar Shack West, two exploration and instrumentation holes were drilled near the back and toe of the pile.

Following discussions with NMED and internal review, two additional drill holes were made in Capulin waste pile to characterize this pile, where acid seepage is currently occurring, to determine how this pile may differ from others. The final location of drill holes for this program and the installed instrumentation was approved by NMED in a letter dated July 7, 1999.

The two drill holes to be completed in scar material have not as yet been drilled.

The drilling methods and procedures were in accordance with those described in Molycorp, 1998, and approved by NMED. All drilling was done under the supervision of a specialist geotechnical engineer and a geologist. A top driven hammer drill advancing a double walled casing was used (9 inch OD, 6 inch ID) with air being introduced through the annulus to return a representative sample up the inner tube (with minimal

breakage of the waste fragments). Samples were collected for each 5 ft advance and split for laboratory testing. The casing was advanced until bedrock was encountered. The decision on when bedrock was encountered was based on a combination of the observations of the driller and rig penetration and the observations of the geologist of the nature of the drill cuttings. The lowest five foot sample therefore represents a mixture of pile material and foundation material. Preliminary drill hole logs are provided in Tables 1 to 9. SRK has provided a report entitled "Preliminary Observations of Mine Waste Rock Piles at Questa New Mexico" dated August 29, 1999. A more detailed description of the drilling procedures and drill hole logs will be provided in a subsequent report.

The drill holes have been plotted on sections through the waste rock piles and these are shown on Figure 5. The bedrock depth has been interpreted from the drill hole data. The shallow depth of the waste rock piles is readily apparent from these sections.

## **2.2 Task 1.4 Instrumentation and Monitoring**

Instrumentation was installed in the drill holes, generally in accordance with the program proposed by MolyCorp, 1998:

- i. The internal PVC casing was reduced in diameter to 1 inch to obtain the flexibility required for instrumentation installation. The casing was slotted at the base and can be used for water sampling, but no water was encountered at the waste pile:bedrock contact in any of the drill holes.
- ii. A string of thermistors was installed in each hole to measure temperature at intervals between 5 and 100 ft depth. These were monitored shortly after installation was completed and the results are plotted on Figure 6.
- iii. A string of pore gas sampling tubes were installed to sample pore gas at the same elevation as the thermistors. No pore gas sampling has been done as yet.
- iv. After an evaluation of the difficulties of achieving reliable readings from moisture content sensors installed in other boreholes elsewhere it was decided that installations to achieve valid readings could not be obtained and these were omitted. Consideration is being given to installing such sensors in deep test pits where the material type and compaction characteristics can be controlled to be representative of the rest of the pile material.

The instrumentation installations proposed were reviewed and approved by NMED prior to installation. A program of monitoring is being implemented in accordance with MolyCorp, 1998. The results will be reported in subsequent reports.

## **3.0 LABORATORY TESTING**

A total of 160 test specimens from the nine drill holes were tested.

The samples were analyzed for water (moisture) content, pH, and conductivity using standard procedures provided by SRK and included in Appendix A.

The following method for laboratory determination of water (moisture) content of soil and rock was used.

- Thermostatically controlled forced draft type oven was used, maintaining a plus or minus 5 degree centigrade at 110 degree centigrade.
- % difference in mass, after successive drying periods, was recorded to ensure insignificant changes in last time period.
- 300 grams of sample were initially used for 83 test specimens and dried for 7 hours. 77 test specimens were analyzed using 50 grams of sample, dried for 2 hours and dried to a constant weight after 1 more hour. The latter test was done to obtain early results for this report. These tests are being repeated using the first (standard) test procedure, but no material changes in results are anticipated.

All samples were passed through a 0.525 mesh screen. Remaining top fractions on the screen were returned to its original bag. Remaining minus fractions were also returned to bag.

All raw calibrations and temperature checks were recorded on a ledger.

The results of this testing for paste pH, conductivity and moisture content is provided on Tables 1 to 9. The results are also plotted against depth for each of the boreholes on Figures 7, 8 and 9.

Further testing in accordance with Task 1.5 is planned and these results will be presented in subsequent reports.

#### **4.0 GEOCHEMICAL CHARACTERIZATION AND POTENTIAL FOR ARD LEACHATE**

Complete geochemical characterization of the four rock waste piles does require the completion of Tasks 1.1 and 1.5. The following is an interim interpretation. This interpretation is for current conditions.

It is anticipated that there will be kinetic changes of ARD potential with time. Thus a profile, which currently has little or no potential for yielding ARD, may yield such drainage at some time in the future. This is as a consequence of changes (or advances) in the location of the acid front. Oxidation and acid generation is a dynamic (or kinetic) process. At the time of mining the waste rock is likely alkaline as a result of the exposed alkaline minerals. The sulfides begin to oxidize only when they are exposed to the oxygen in air and water. Oxidation is slow, particularly initially (prior to the onset of bacterially catalyzed oxidation which occurs only after the pH falls below 4.5). The initial small amounts of acidity which are produced are neutralized by the available alkalinity in the waste rock. Only if acid generation has advanced to the extent that all the alkalinity is consumed does the rock waste actually become acidic. If acid is leached from an acidic zone and transported into an adjacent alkaline zone it consumes reserve alkalinity resulting in the advance of an acid front. If this acid front advances to the base of the waste rock pile then seepage from the base of the pile will be acidic.

The assessment of future ARD drainage potential requires the completion of the characterization work, particularly the kinetic testing of Task 1.5 as well as the modeling and prediction work that follows in Task 1.8.

#### 4.1 Spring Waste Rock Pile

Based on the surface characterization studies (SRK, 1996; Wagner & Harrington, 1995) it was anticipated that WRD-1 would be principally in aplite and black andesite waste and non-acid generating (Zones 151 to 154). WRD-2 would be expected to be in mixed volcanics and aplite (Zones 187 to 189) and acid generating. The results from WRD-1 and 2 (locations shown on Figure 2) confirm this.

**WRD-1** was completed in aplite and black andesite that has undergone propylitic alteration (see SRK 1999). The andesite cuttings locally contain pyrite, chalcopyrite and molybdenite. Calcite was consistently present in the andesite. None of the mixed volcanic material was observed.

The paste pH results (Figure 7) shows values consistently above 7, conductivity (Figure 8) is moderately low (less than 2,500  $\mu$ S) suggesting a moderate TDS. The temperature profile (Figure 6) ranges from 60° to 55° F suggesting that there is negligible heat of oxidation. These are all indications of non-acid generating characteristics. This characterization will be confirmed with static (ABA) testing.

**WRD-2** was completed in mixed volcanics, characterized by altered rock fragments in a yellow-brown clay rich matrix. Locally pyrite could be observed.

The paste pH tests (Figure 7) were consistently low (generally less than 4) and high conductivity (Figure 8) values were recorded, particularly near the base of the pile. In contrast to WRD-1 the temperature in WRD-2 increased with depth to approximately 90° F. These are all indications of substantial oxidation.

For acidic drainage to be occurring from the base of the pile at the location of the drill hole, two conditions must exist:

1. The waste rock at the base of the pile must be acidic ( $\text{pH} < 4.5$ ), and
2. There must be downward migration of water (seepage) to transport acidic leachate from the base of the pile into the foundation materials.

If the upper part of a waste rock pile is acidic but the lower part is neutral or alkaline then the lower waste zone will neutralize any acidic seepage entering into it. When the neutralization capacity of upper layers of such a zone is consumed they become acidic resulting in the acid 'front' migrating downwards. The rate at which the acid front migrates depends on:

1. The acidity of the seepage,
2. The quantity of seepage, and
3. The neutralizing capacity of the acid neutralizing waste rock.

If there is no downward migration of seepage then there will be no movement of the acid front.

Based on the drill hole information it is apparent that the upper bench of Spring Gulch waste rock pile is acidic throughout its profile and at the base. This does not mean that there will be acid mine drainage from the base of the pile as the mechanism for leaching, and downward migration of contaminants, must also be there. This potential is considered further in Section 5 below.

Since WRD-1 and 2 are entirely in acid consuming and acid generating waste rock respectively, they serve as useful references against which to compare other drill hole results.

#### 4.2 Sugar Shack South Waste Rock Pile

WRD-3 to 5 were drilled in this pile at the locations shown in Figure 3. From the surface characterization studies it was anticipated that the upper part of WRD-3 would be in non-acid generating aplite (Zone 88, in the aplite wrap-round berm) and the lower part in potentially acid generating mixed volcanics (Zone 66 and 87) resulting in low (or no) ARD potential in the top and high ARD potential at depth. WRD-4 was expected to be mainly in mixed volcanics (Zone 66) with high ARD potential, and WRD-5 in mixed volcanics and andesite resulting in high ARD potential. These expectations were substantially confirmed in these drill holes.

**WRD-3** was drilled near the toe of the pile, primarily in fresh aplite for the upper 55 ft with hydrothermally altered mixed volcanic material near the base of the hole. The paste pH and conductivity (Figures 7 and 8) clearly reflect these materials. It should be noted that the pH in the lower section is not nearly as low, or the conductivity as high as is observed in WRD-2, indicating that the current acidity and oxidation conditions are much milder than the conditions pertaining in WRD-2. The temperature profile (Figure 6) reflects some increase in temperature over that observed in WRD-1 but is considerably less than that in WRD-2. In WRD-3 the acid front is above the base of the pile.

**WRD-4** is located at pile mid height, and intercepted hydrothermally altered mixed volcanics and lesser amounts of fresh aplite. Despite the apparent potential for acid generation the pH values are generally quite high (above 4.5 and often above 7). Conductivity values are also moderate. The layers near the base of the pile have pH values above 7. It is apparent therefore that the acid front is high above the base. The temperature profile indicates a rapid increase in temperature with depth to over 100° F at the base. This indicates that there is oxidation and heat generation occurring in the airflow pathway between drill hole WRD-3 and 4. During drilling and prior to removal of the drill stem, hot air was observed to discharge from the drill pipe (SRK, 1999). Because the drill stem was closed and continuous from the surface to the bottom of the hole, the airflow originated at the base of the waste rock pile. This illustrates the relatively high air permeability that exists in the coarse rock zone at the base of the dump and the freedom with which air can move through the dump under the pressure gradients that develop naturally as a result of differences in air density due to temperature differences (chimney effect).

**WRD-5**, located near the top of the pile, intercepted clay altered material near the surface and fresh porphyritic andesite with calcite at depth. From the paste pH and conductivity profiles it is apparent that oxidation and acid generation is occurring near the top of the pile but that it is being controlled by the calcite (calcium carbonate neutralization) at depth. The acid front is high in the pile. The temperature profile

reflects a steady increase with depth to temperatures over 110 °F at the base. This indicates that oxidation is ongoing in the airflow pathway between WRD-4 and 5.

#### 4.3 Sugar Shack West Waste Pile

**WRD-6 and 7.** From the surface characterization studies it was anticipated that WRD-6 and WRD-7 would be completed in granitic andesite (Zone 40). The material was therefore expected to have moderate acid generation potential.

In both holes, clay altered mixed volcanic materials were encountered to a depth of about 30 ft. At depth the rock appeared to be fresher mixed volcanic material.

Both holes show identical paste pH and conductivity profiles, reflecting that both profiles were developed from the same materials piled from the same platform at the same time. The acid front in this pile is high, well above the base of the pile, and conductivities are relatively low.

The temperature profiles are quite different; with the temperature in WRD-6 being slightly elevated (compared with WRD-1) while that for WRD-7 is considerably elevated. Since there is little potential for fresh air (with oxygen) entering high through the face of the pile (against the thermal gradient) it appears to confirm the mechanism that air enters the base of the pile in the highly permeable base layer and migrates upwards in this base layer (hence causing the most oxidation and temperature rise in this layer), increasing in temperature with added oxidation along the flow path, to finally vent through the upper surface of the dump. This mechanism is illustrated in Figure 10a. Thus the temperature in WRD-6 is somewhat elevated, but less so than WRD-7, despite the similarity in geochemical characteristics in both drill holes. The results of oxygen and carbon dioxide monitoring, as well as the thermal variation with colder (winter) source air will considerably assist in the definition of the airflow and oxidation patterns in the rock piles.

#### 4.4 Capulin Waste Rock Pile

**WRD-8.** From the surface characterization, the waste rock in Capulin pile at WRD-8 was expected to be granitic andesite with ARD potential (Zone 3B). The material encountered was a crystal rich tuff with altered, clay rich matrix. Sulfide mineralization was more common at this location (SRK, 1999). Paste pH was uniformly low (below 4), but conductivity was moderate. The temperature increased with depth to temperatures in excess of 90° F at 100 ft.

**WRD-9.** From the surface characterization, the waste rock was expected to be acidic andesite of variable color (Zone 7). Lithologies encountered were mixed volcanics, tuff and black andesite. Cuttings from the upper 25 ft contained altered clay. Fresher materials were encountered at depth. There was a moderate increase in temperatures with depth.

With both WRD-8 and 9 the acid front is at the base of the pile.

#### 4.5 Conclusion Regarding Acid Front in Waste Rock Piles

The current location of the acid front in the piles at the investigative drill hole locations is at the base of the pile only for WRD-2, WRD-8 and WRD-9. For the remainder of the drill hole profiles the acid front appears to be located well above the base of the piles.

#### 5.0 ARD MIGRATION

In order to drain contaminants from the pile, there must be a downward migration of water to leach them and transport them into the environment.

In recent years there has been an increasing recognition of the effects of evaporation and evapotranspiration in controlling the rate of infiltration through surficial soils, particularly in arid and semi arid climates where the net infiltration may become very small. Surface evaporative effects reduce the net infiltration into the Questa waste piles.

However, there is another effect that may be of particular significance at Questa. This is the potential drying effect of convective air transfer through the piles. Piles constructed by dumping over a crest, such as was practiced at Questa, results in segregation on the pile face such that the large boulders accumulate at the base and there is a concentration of finer material at the top. This typically results in a very high air permeability layer of coarse large boulders at the base of the pile. When more coarse durable rock is mined the entire pile slope may be composed of coarse waste rock. With this configuration, a permeable (to air) layer or 'chimney' develops to the pile surface. This is illustrated in Figure 10a. Such chimneys are often observed on acid generating piles when they yield vents of 'steam' during cool winter days. The steam from the vent represents air that has entered (in a cool relatively dry state) at the base of the pile and traveled through the coarse boulder layers (warming as it contacts the warm waste which has elevated temperatures as a result of the exothermic pyrite oxidation reactions) and then passed up the chimneys as warm air. The increase in air temperature results in its expansion and decrease in density, producing the pressure gradients and draft effect in the chimneys, drawing in more air at the base. The warm air also brings in fresh oxygen that increases the rate of oxidation and hence perpetuates the oxidation, temperature increases and draft effect. The air is also responsible for the transfer of heat through the dump. The air picks up heat in zones where oxidation reactions are occurring and transfers it, along its flow path, to the rock through which it flows. Increasing temperatures between two drill holes are therefore an indication of oxidation reactions in any flow path between the two drill holes, but the temperature at a particular hole in a 'hot' air stream does not necessarily indicate oxidation of the waste in which that hole is located. This is analogous to the heating up of a household chimney even though the chimney itself is not on fire.

The cool dry air, as it heats up, is able to increase its relative humidity and increase its water vapor content. As this warm humid air leaves the pile, at the surface the moisture may condense producing the observable steaming vents. Such vents have been observed at Questa and at numerous other acid generating waste piles. In most cases the exhalation rate is too slow to produce visible vapor. At typical pile temperature ranges of between 60 and 140° F a cubic meter of air at saturation will hold between 15 and 150 ml of water respectively. Thus if we assume that each cubic meter of air passing through the pile increases its moisture content by 50% of its warm saturated

capacity, then this amounts to about 75 ml per cubic meter of air. Assuming the infiltration into the Questa piles is 20% of precipitation (i.e. 20% of 40 cm {16 inches} of rainfall) then the total infiltration is about 80,000 ml per square meter per year. To remove this volume of water by evaporative airflow at 75 ml per cubic meter would require an airflow rate of 80,000/75 cubic meters per year per square meter. This represents a flow rate of  $80,000/75/365/24/60 = 0.002$  m per minute or 2 mm per minute. The airflow through the pile may not be uniform but may occur principally through the coarser chimneys.

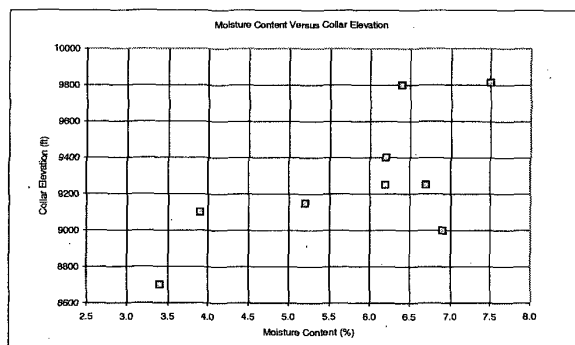
The piles at Questa differ from other piles in that they are very high and shallow. This is well illustrated by the sections for Sugar Shack South and West piles in Figure 5. For these piles the typical pile material thickness is less than 100 ft, while the pile height is well over 500 ft. In more conventional piles, the average pile thickness is about the same as the pile height. The chimney effect is therefore very large for the Questa piles. The increase of temperature with depth at Questa indicates that very active oxidation and temperature generation is occurring in the lower layers of the piles. The permeability of this lower layer and the active venting is clearly illustrated by the experience at WRD-4 with the venting from the drill pipe.

Other than the Capulin waste pile there is remarkably little evidence of seepage from the Questa waste piles. No toe seeps are observed and there appears to be no detectable mounding of the water table at the toes of these piles. One cause of this lack of seepage may be the drying effects of thermal venting through these waste piles.

One of the objectives of this investigation was to evaluate moisture conditions in the piles to determine if thermal venting could be controlling the potential for contaminated drainage from the piles. To investigate this factor, the waste samples from the drilling program were carefully collected to preserve their moisture content and the moisture content was determined in the laboratory. The results are summarized on Tables 1 to 9, and presented in graphical form in Figure 9.

The average moisture content for each of the drill holes is as follows:

Drill Hole	Moisture content (%)	Elevation of top of hole (ft)
WRD-1	3.9	9100
WRD-2	6.7	9250
WRD-3	3.4	8700
WRD-4	5.2	9150
WRD-5	6.2	9250
WRD-6	6.9	9000
WRD-7	6.2	9400
WRD-8	7.5	9814
WRD-9	6.4	9800



From a view of the plots of moisture content with depth (Figure 9) and the results in the above table, it can be observed that generally there is:

- A low overall moisture content,
- A decrease in the moisture content in the holes at lower elevations (above table and graph),
- A decrease in the moisture content in the profiles of each hole, particularly near the base (Figure 9).

This appears to indicate that there is a drying effect at the base of the piles. In all cases the foundation rock was dry and dusty when drilled. No water was encountered at the base of pile:bedrock contact. The drying effect appears greatest for the lower piles where the precipitation is also lower. This enhanced drying may also be the result of drier air at the point of entry.

There are a number of factors that determine the moisture content in soils and mine waste rock. These include the density, grading (grain size distribution) and clay content. Drained field moisture contents (the amount of water that a freely drained sample of the soil will hold) typically range from over 40% for clays to about 20% for many loams (soil mixtures - silty and clayey sands) to about 5 to 8% for clean sands and gravels. To achieve moisture contents below the drained field moisture content requires the application of suction. Plants apply such suction by osmosis through root cell walls. Evaporation from the surface of the waste rock pile also applies suction (negative pore water stress) through the pile. Air movement through the pile would also cause evaporation in the interior of the pile, further increasing the soil suction. The moisture content, hence the soil suction, that develops in a waste rock pile represents the net effect of infiltration, evapotranspiration from the surface and internal drying caused by air movement through the pile. The lower the moisture content, the higher the soil suction that develops. A soil mass in which there is high pore suction does not yield seepage (much as a slightly moist sponge holds water by 'pore suction'). The coarse waste rock at the base of the pile cannot sustain soils suction and represents a suction break layer, preventing the downward migration of moisture held by pore tension in the waste rock pile.

The very low moisture contents of the lower coarse waste layer and the bedrock may indicate that this is an effective drying layer and suction break layer between the pile and the foundation materials. It is noted that WRD-8 and 9 (the highest pile locations) have high average moisture contents. Only in WRD-8 is there not a very substantial decrease in the moisture content near the base of the pile. This hole is located in the pile with the only clear evidence of toe seepage. Even for this pile it is uncertain if the toe seepage originates mainly from the pile or from groundwater, as there are a number of natural springs observed at the same elevation as the pile, either adjacent to the pile or in the pit on the opposite side of the ridge from the pile.

While considerable monitoring and work still has to be done to assess the effect of drying due to air convection through the piles, there appears to be considerable evidence that such drying is occurring which, together with surface evaporation, is controlling migration of water through the piles.

The proposed program of laboratory testing for this geotechnical and geochemical characterization program (Molycorp, 1998) will investigate the moisture content:soil suction relationships for the mine waste rock. A test plot program is provided for (response to Comment A10, Molycorp, 1998), to specifically determine the conditions that govern infiltration and moisture migration into the mine waste rock, water balance in waste rock piles and seepage from them. Parameters determined from the laboratory test program and the field test plots program, as well as the results from the instrumentation monitoring from this program, will be used to assess and model moisture migration (hence potential for ARD migration) through the waste rock piles.

## 6.0 RESLOPING ISSUES

The data gathered in this investigation enables a first qualitative assessment of the potential for resloping of the Questa waste piles to be made.

In general the topography is not conducive to resloping of most of the piles. From the sections through the Sugar Shack piles (Figure 5) it is apparent that resloping, to say 2:1, would extend the toe considerably. Space for this extension is not available for the piles adjacent to the Red River.

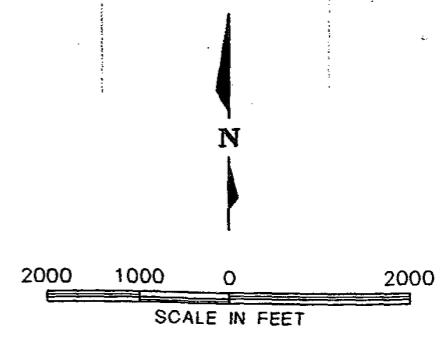
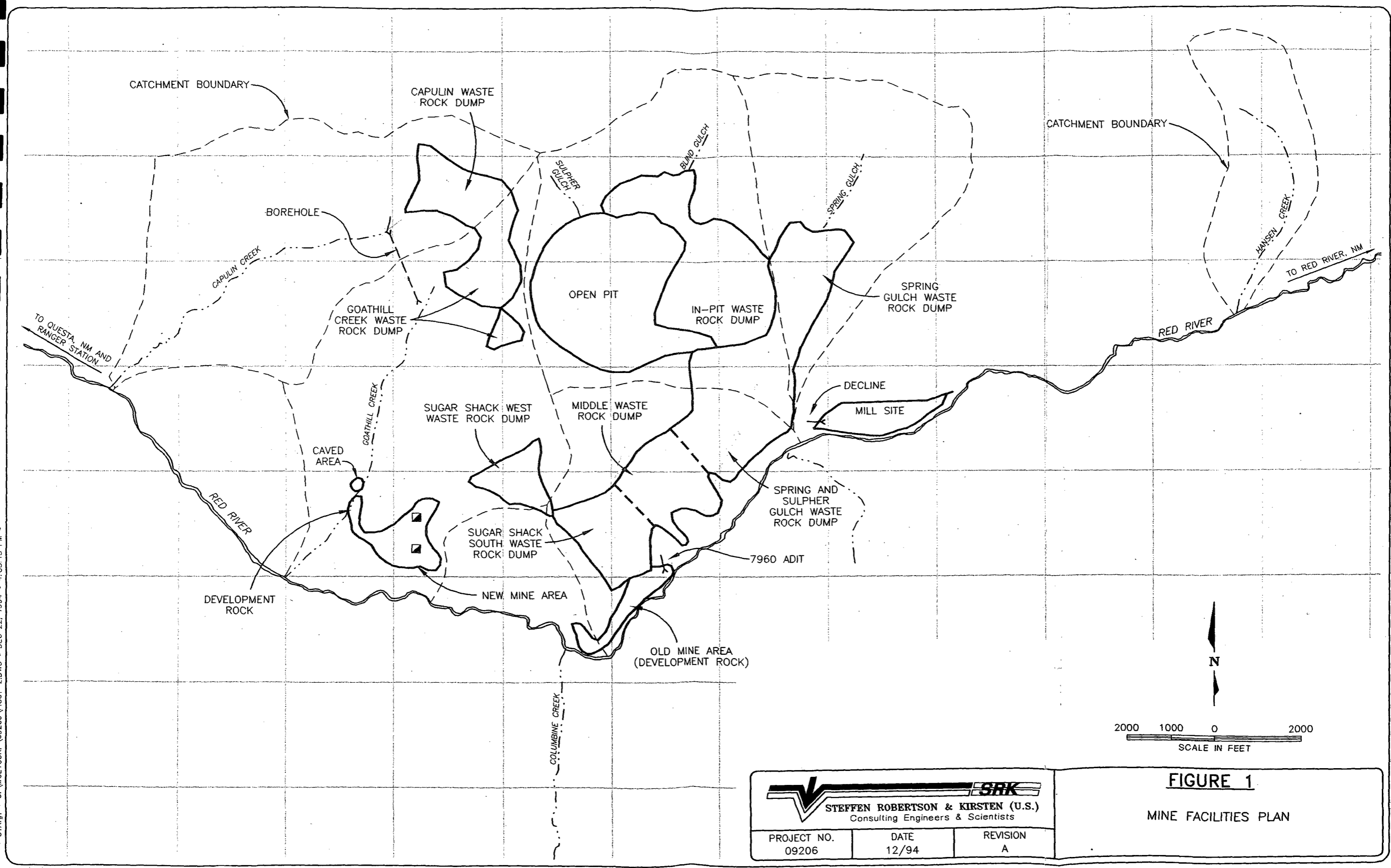
Resloping of many of the piles, by the most practical and generally only economic method of pushing down material from the top, would, for most piles, result in pushing acid generating material from the upper piles over the non-acid generating wrap around berms which form the lower piles (for example Sugar Shack South and Spring Gulch piles).

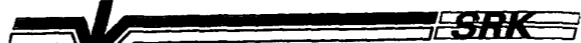
The resloping of piles will result in fine material from the top of the pile being pushed over the coarse lower air permeable layer (as illustrated in Figure 10b). This would reduce the potential for air entry and thermal convective drying in the piles. If this was done without a clear understanding of the potential contaminant yield to groundwater and toe seepage then this could result in contaminated seepage yields and a degradation of the groundwater.

From the above discussion it is clear that it is essential that resloping should be considered and implemented, if appropriate, only after a full appreciation has been obtained of the geochemical and geotechnical behavior of the waste rock and potential remediation measures. The proposed geochemical and geotechnical characterization and closure measures evaluation program provides for the development of this appreciation.

## FIGURES

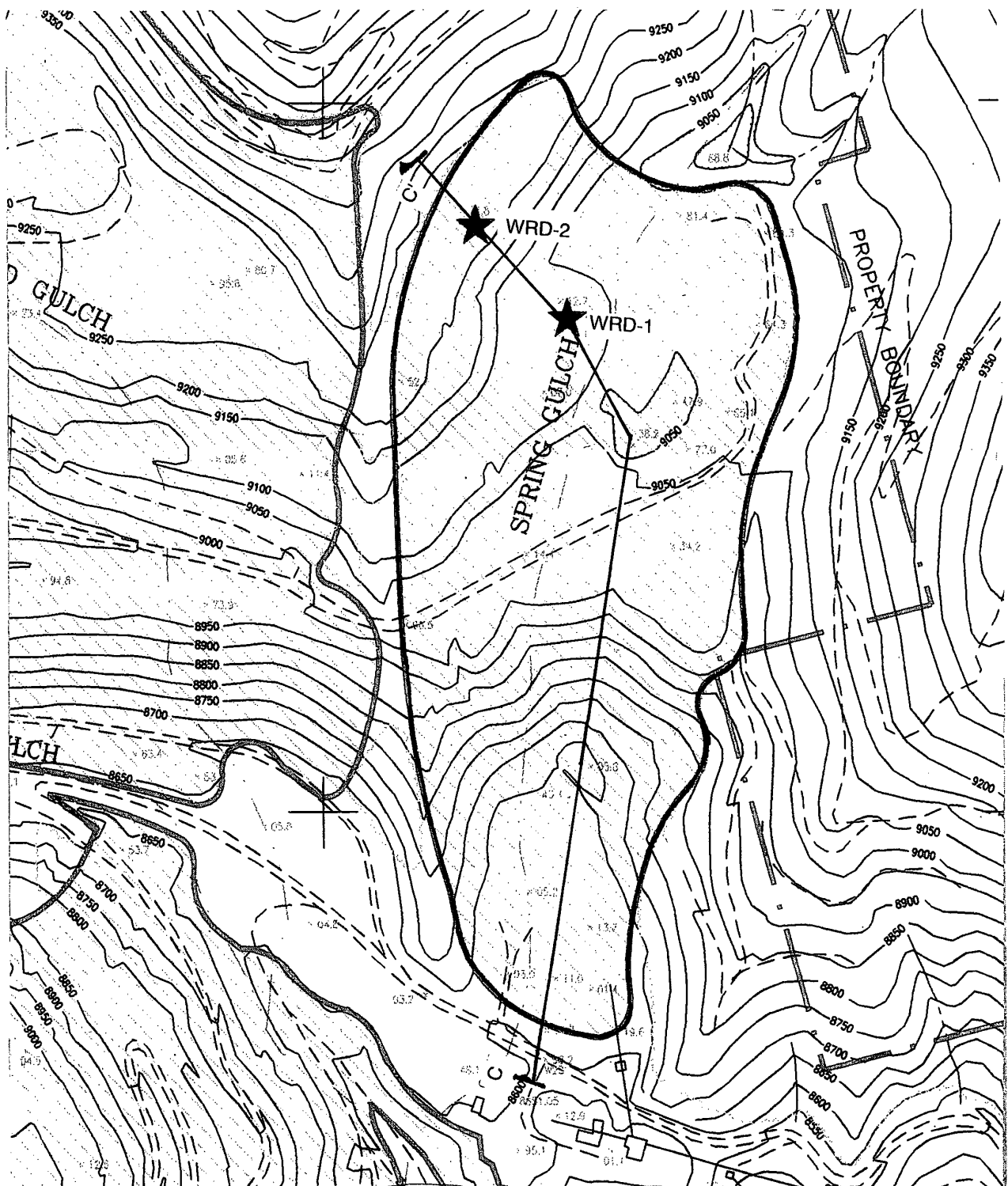
\* STA. #1 \* C:\MOLYCORP\09206\FIG01-2.DWG \* DEC 22, 1994 \* 4:03:13 PM \*



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Consulting Engineers & Scientists

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**FIGURE 1**  
MINE FACILITIES PLAN



Scale 1 in = 500ft  
0 500 1000



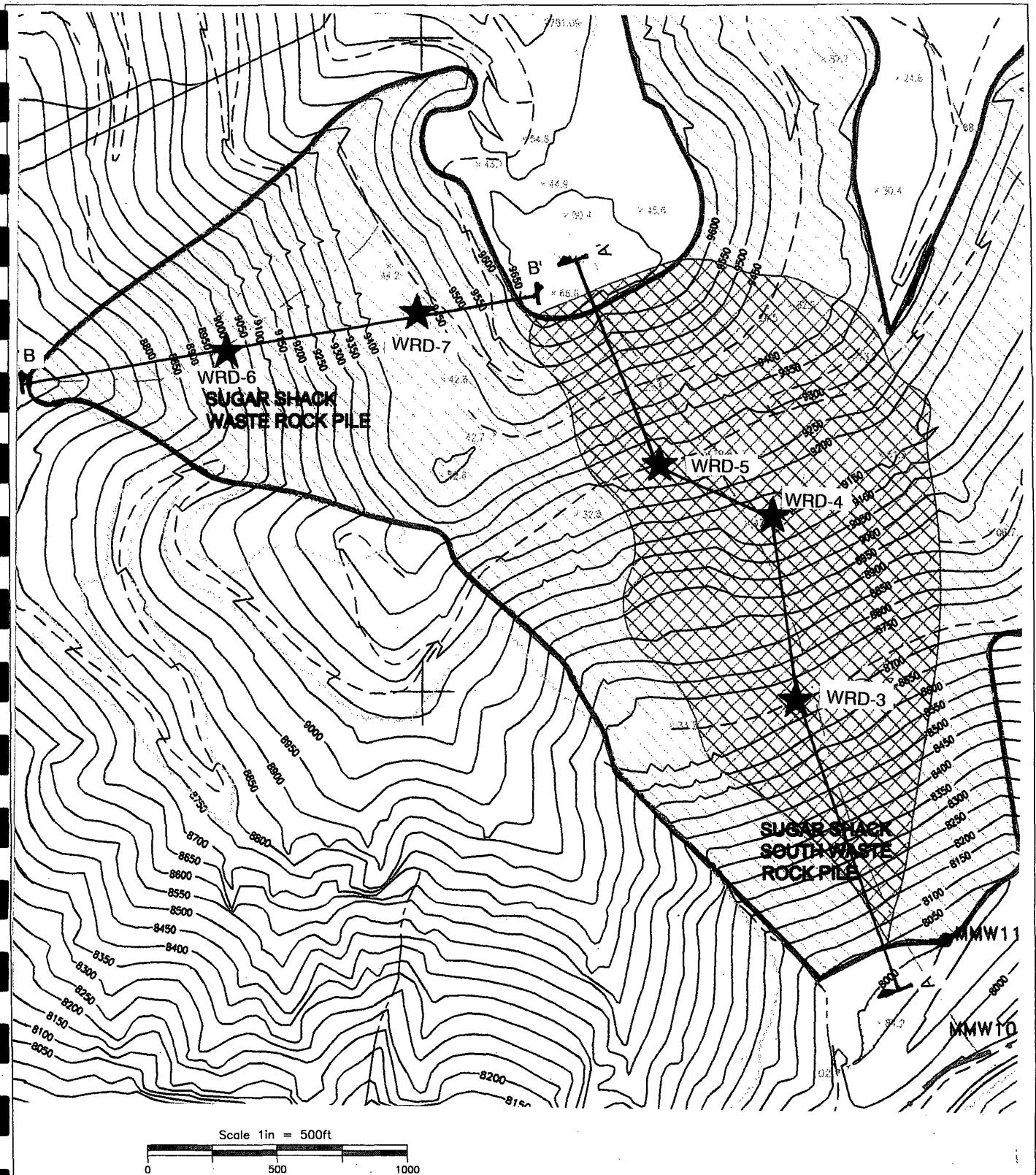
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Waste Rock Pile Geochemical Characterization

**Figure No. 2**  
**Drill Hole and Section Locations:**  
**Spring Gulch Waste Rock Pile**

PROJECT: 052007	DATE: Sept. 99	DRAWN: JG	SCALE: as shown	DWG. NO.:
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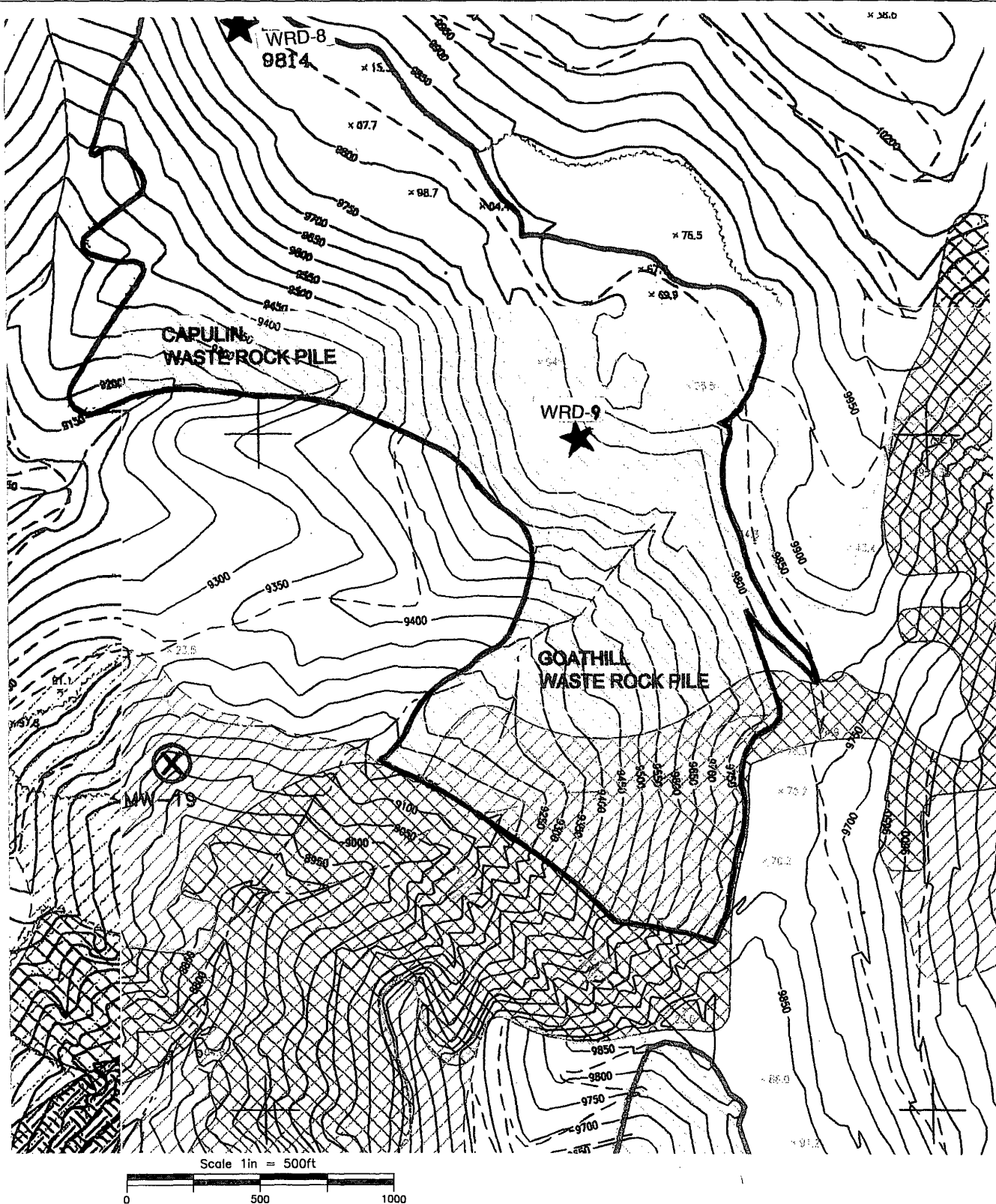
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Waste Rock Pile Geochemical Characterization

**Figure No. 3**  
**Drill Hole and Section Locations: Sugar**  
**Shack Waste Rock Pile (West and South)**

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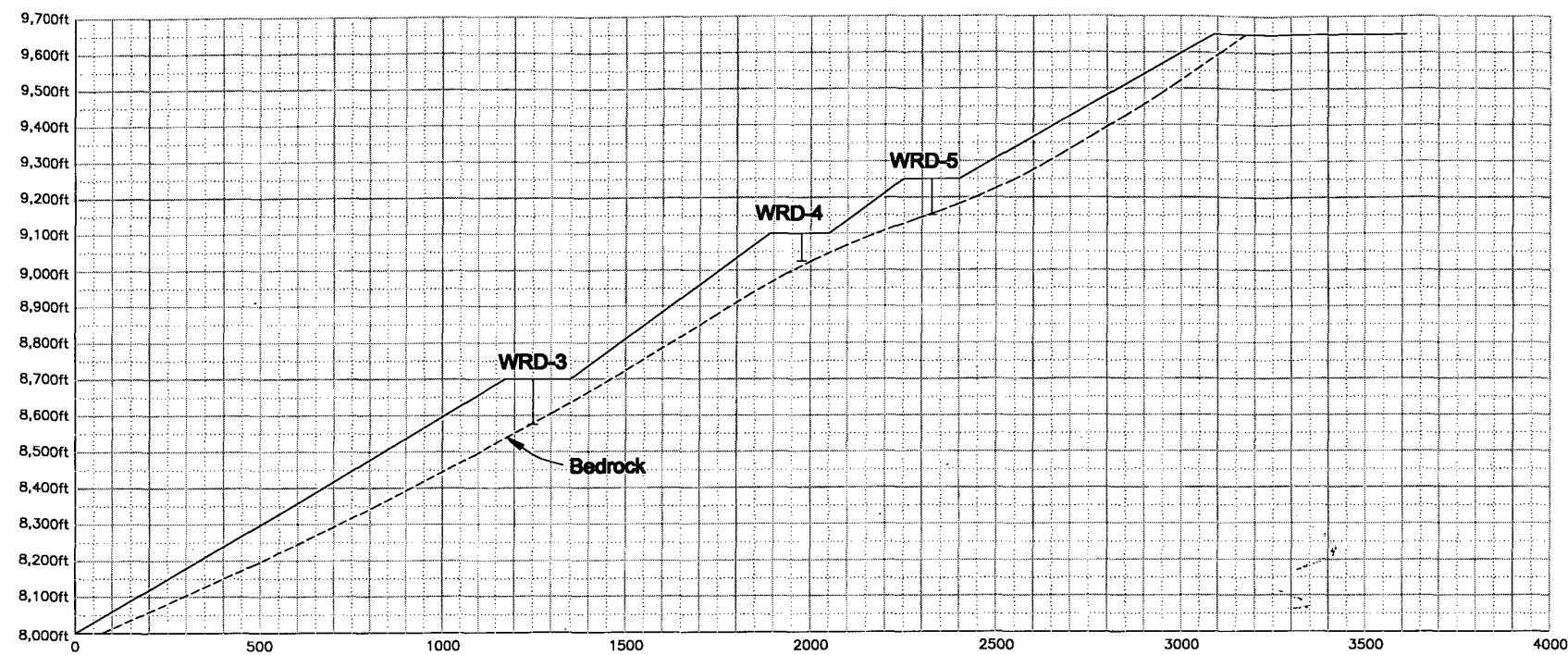
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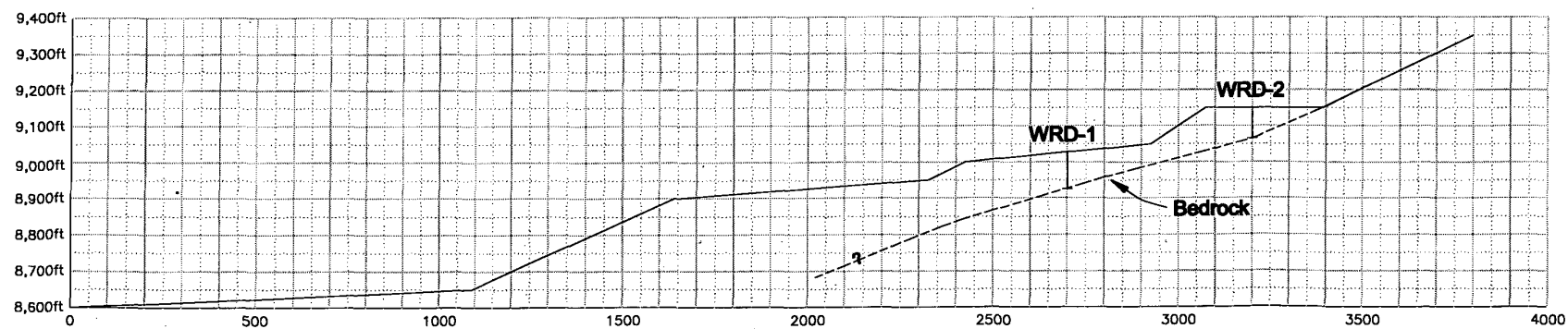
#### Waste Rock Pile Geochemical Characterization

**Figure No. 4  
Drill Hole Locations:  
Capulin Waste Rock Pile**

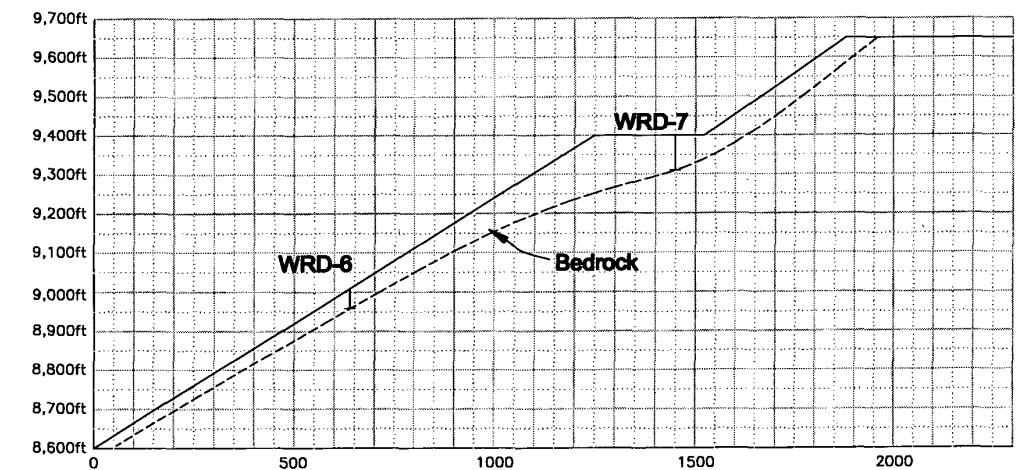
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Section A-A'. Sugar Shack South: Section through Instrumented Boreholes



Section C-C'. Spring Gulch: Section through Instrumented Boreholes



Section B-B'. Sugar Shack West: Section through Instrumented Boreholes

Note:  
For section Locations see Figures 2 and 3

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Waste Rock Pile Geochemical Characterization

**Figure No. 5  
Sections through  
Instrumented Bore Holes**

PROJECT: 052007	DATE: Sept. 1999	DRAWN: JG	SCALE: as shown	DWG. NO.
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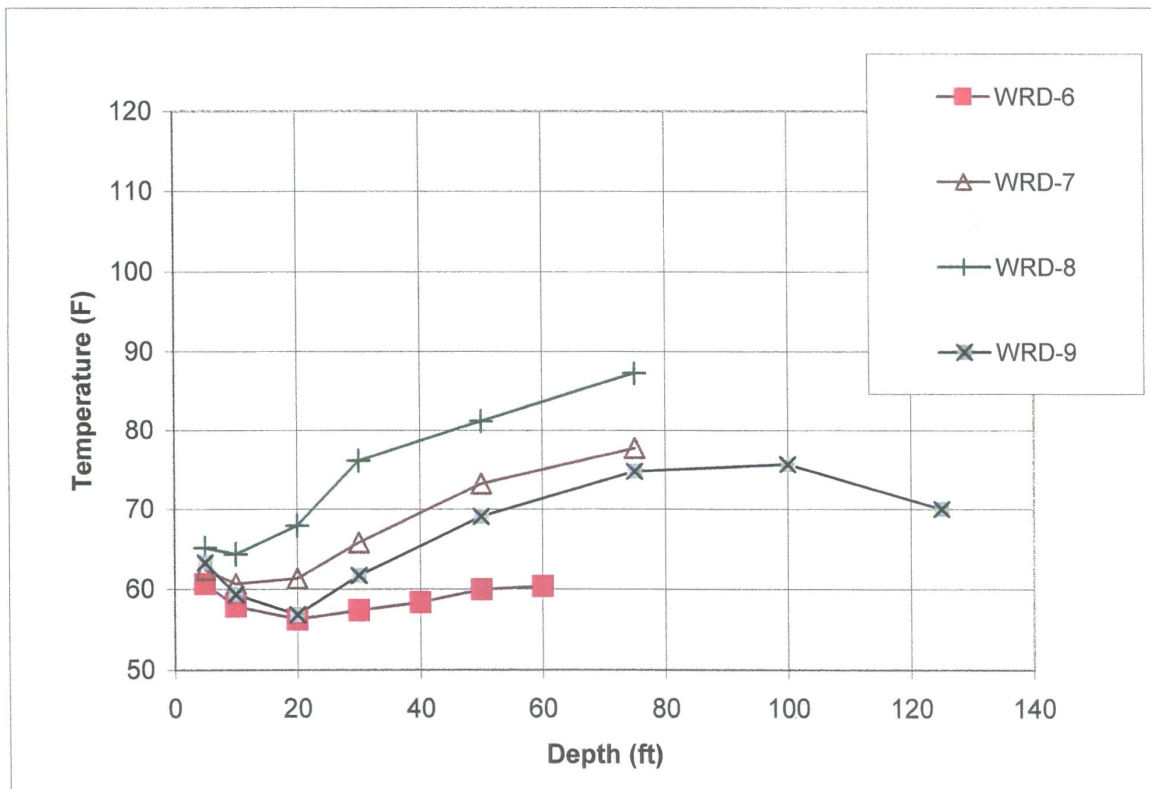
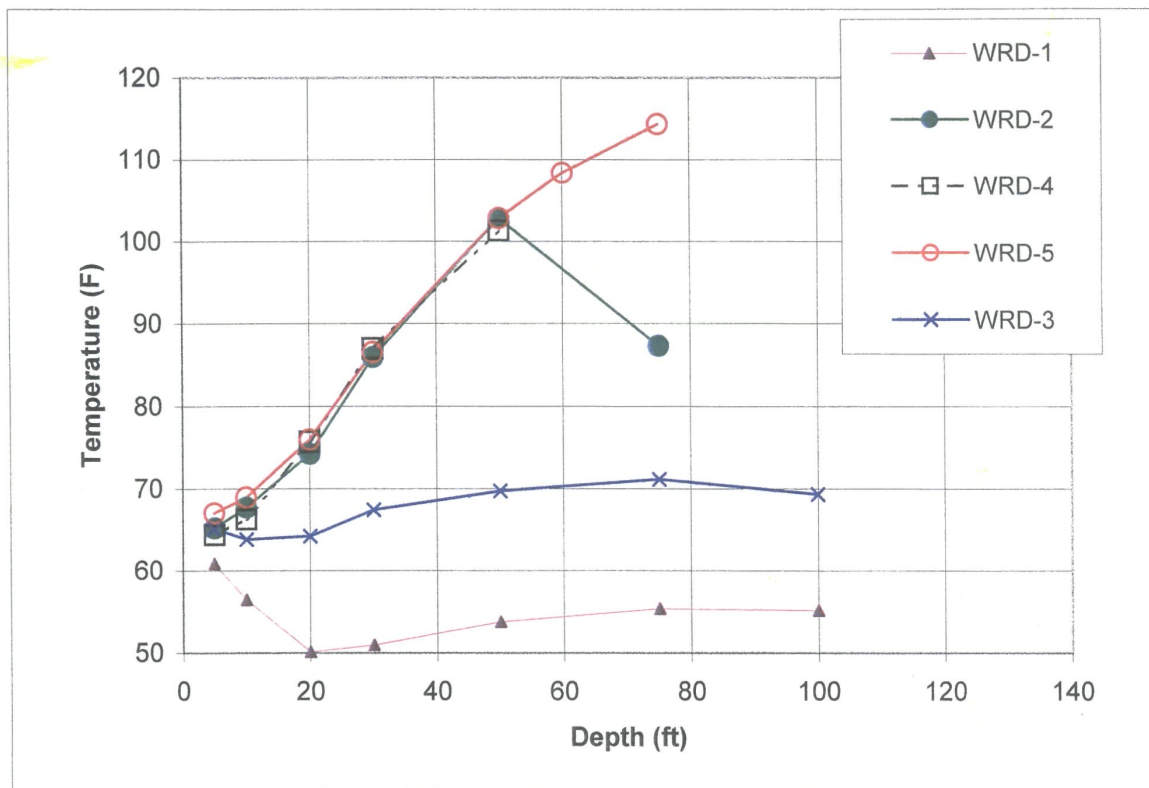


Figure 6. Temperature Versus Depth

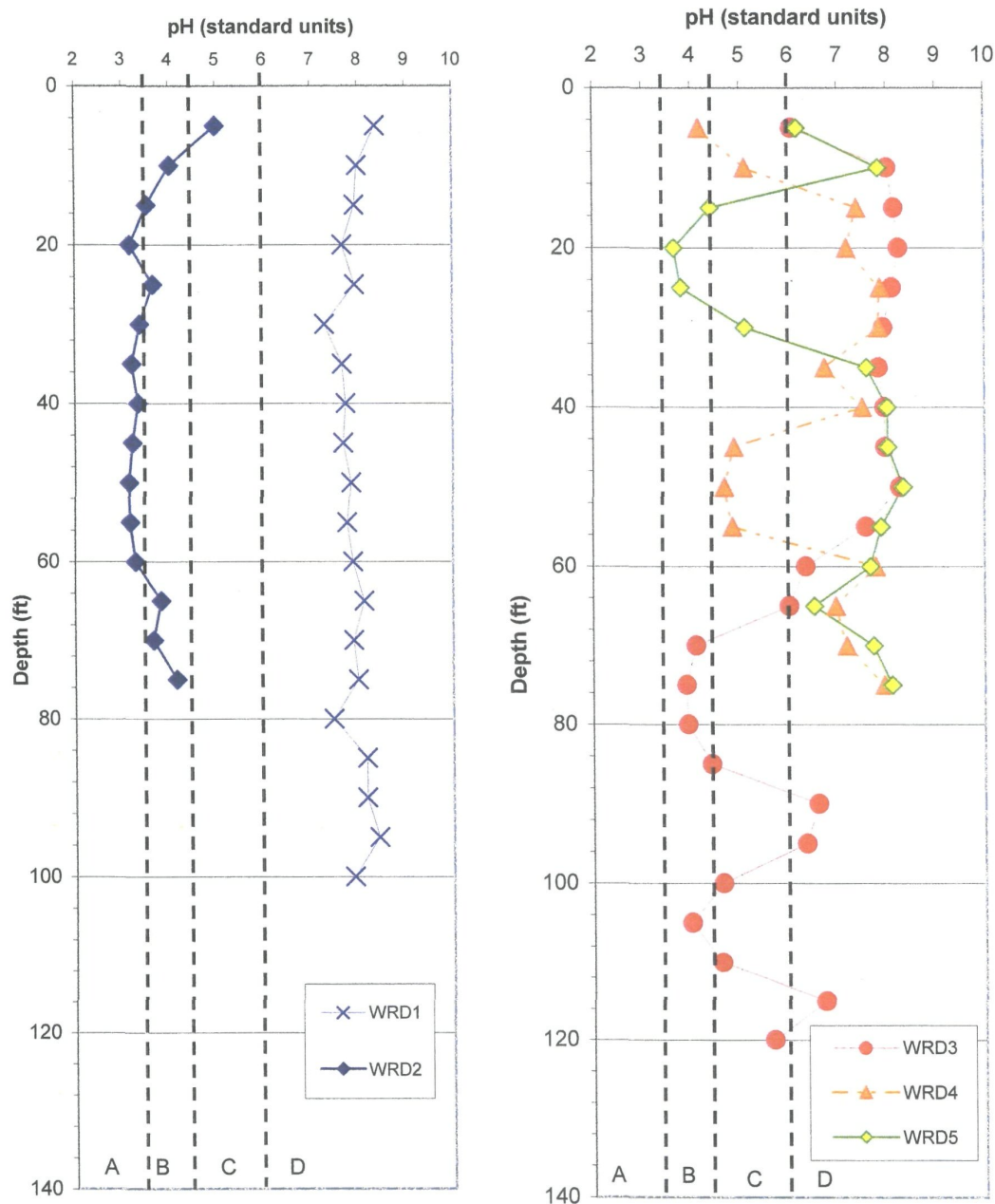
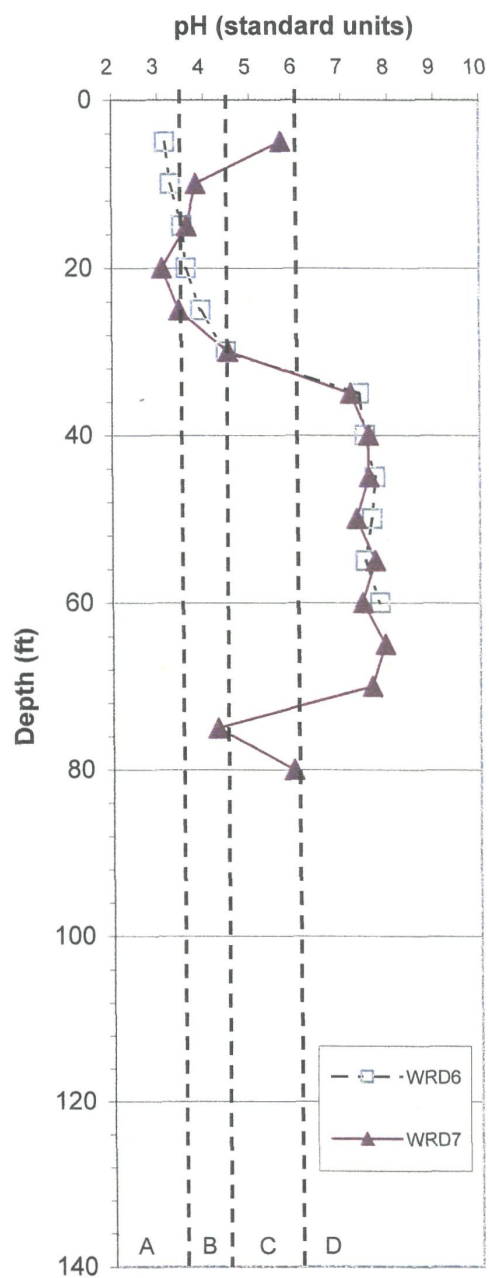
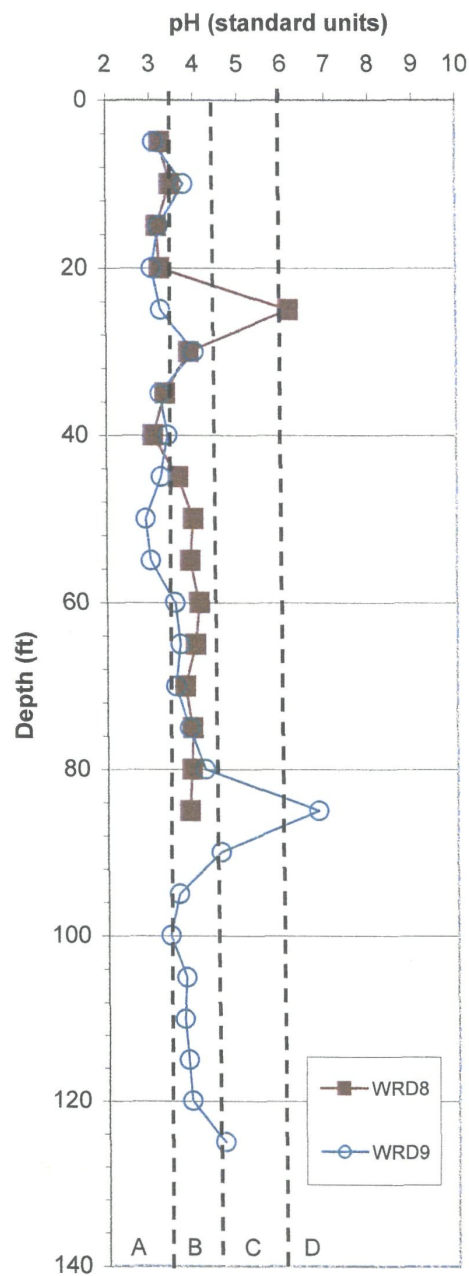


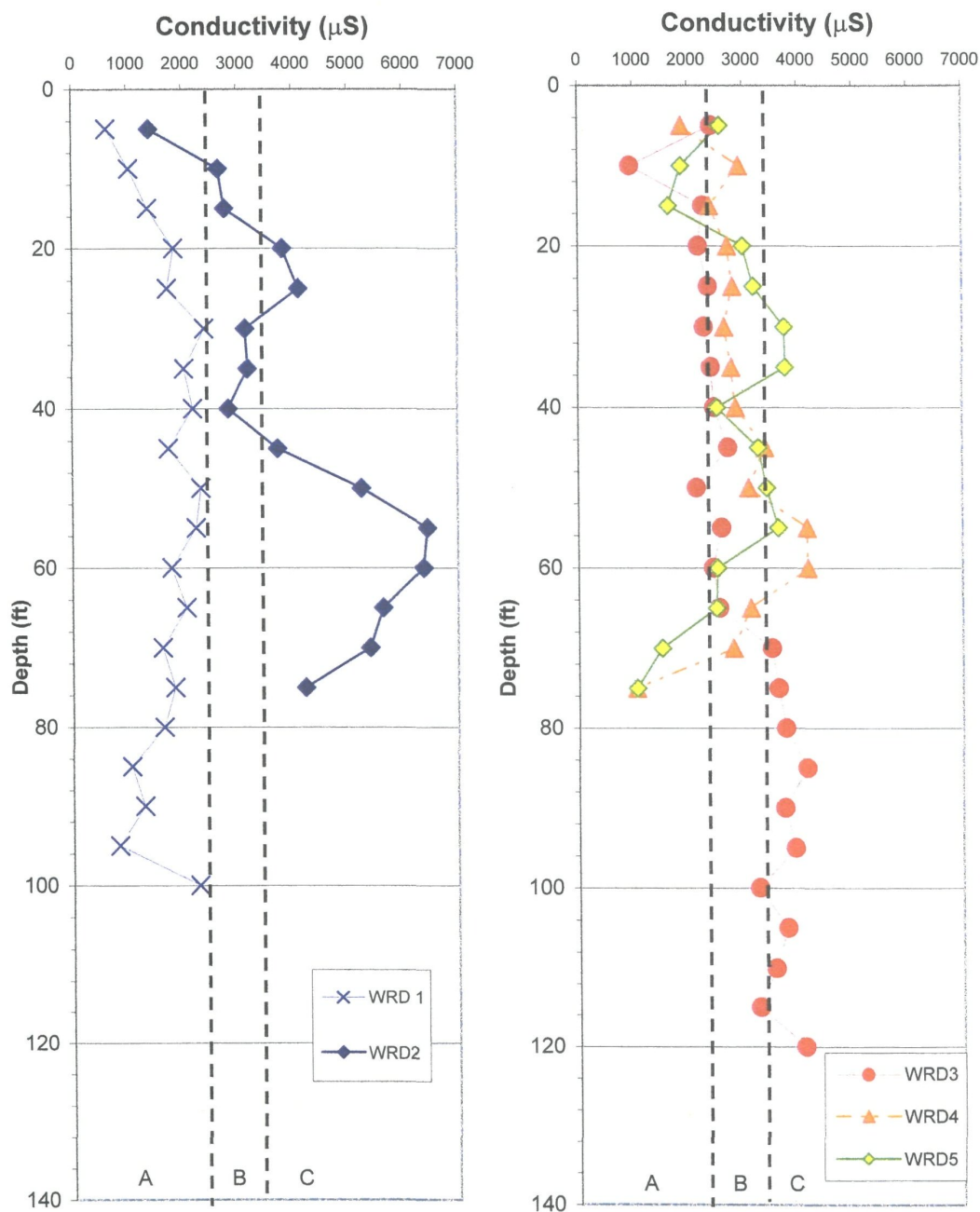
Figure 7a. Paste pH versus Depth



ZONE A = pH < 3.5 (strong acidity)  
 ZONE B = pH between 3.5 and 4.5 (moderate acidity)  
 ZONE C = pH between 4.5 and 6 (weak acidity; likely low metals)  
 ZONE D = pH > 6 (non-acid)



**Figure 7b. Paste pH versus Depth**



**Figure 8a. Conductivity versus Depth**

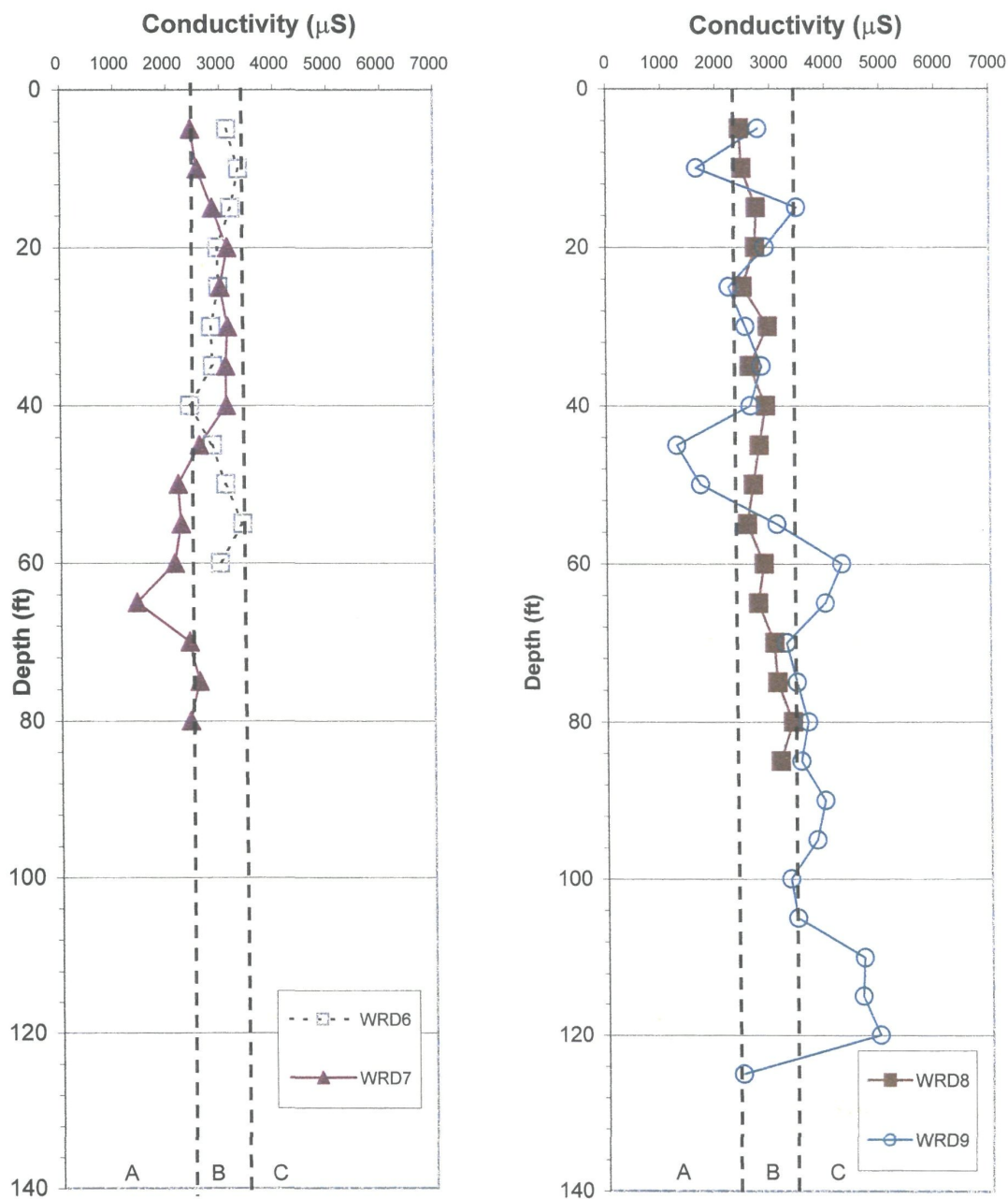


Figure 8b. Conductivity versus Depth

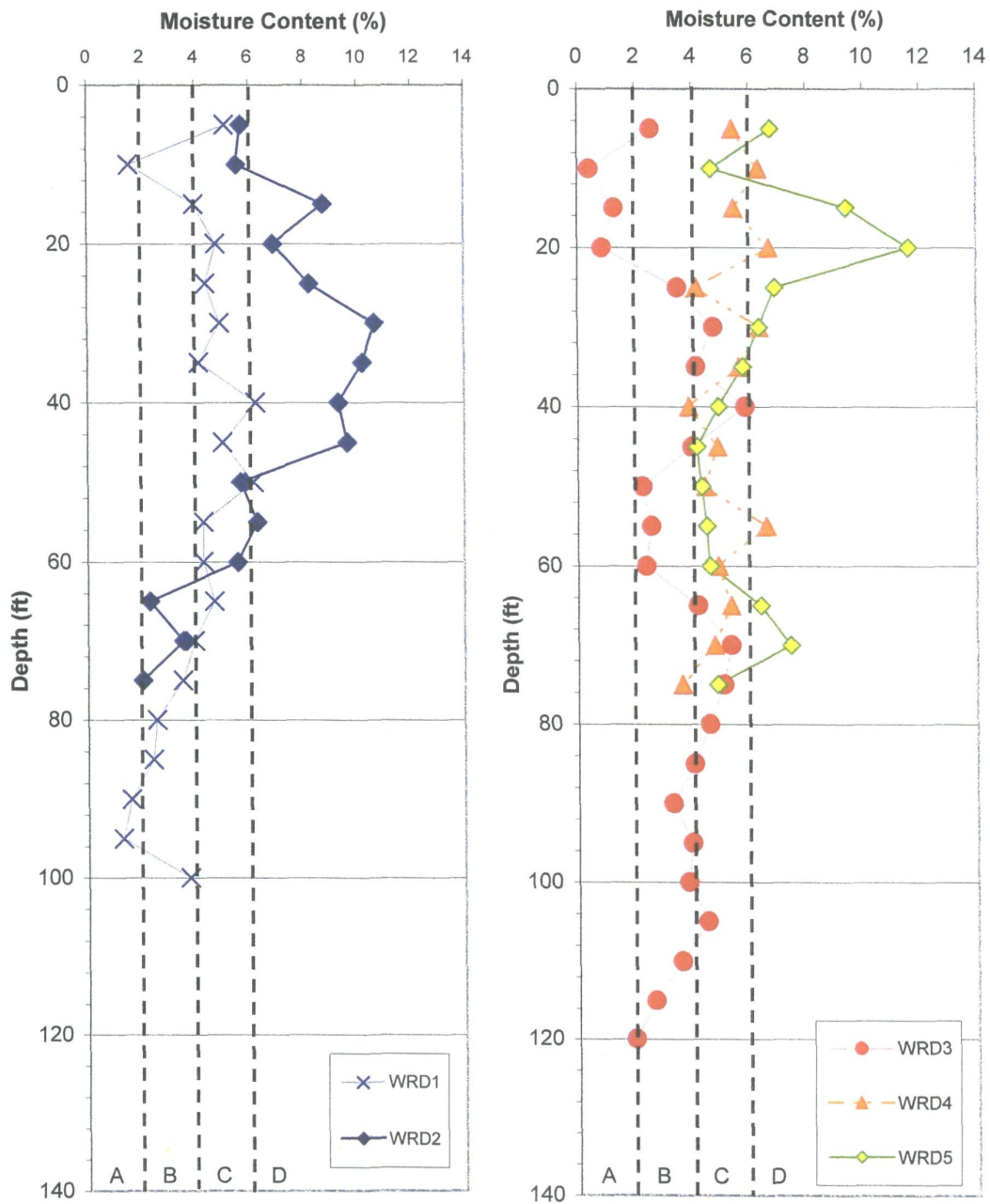


Figure 9a. Moisture Content versus Depth

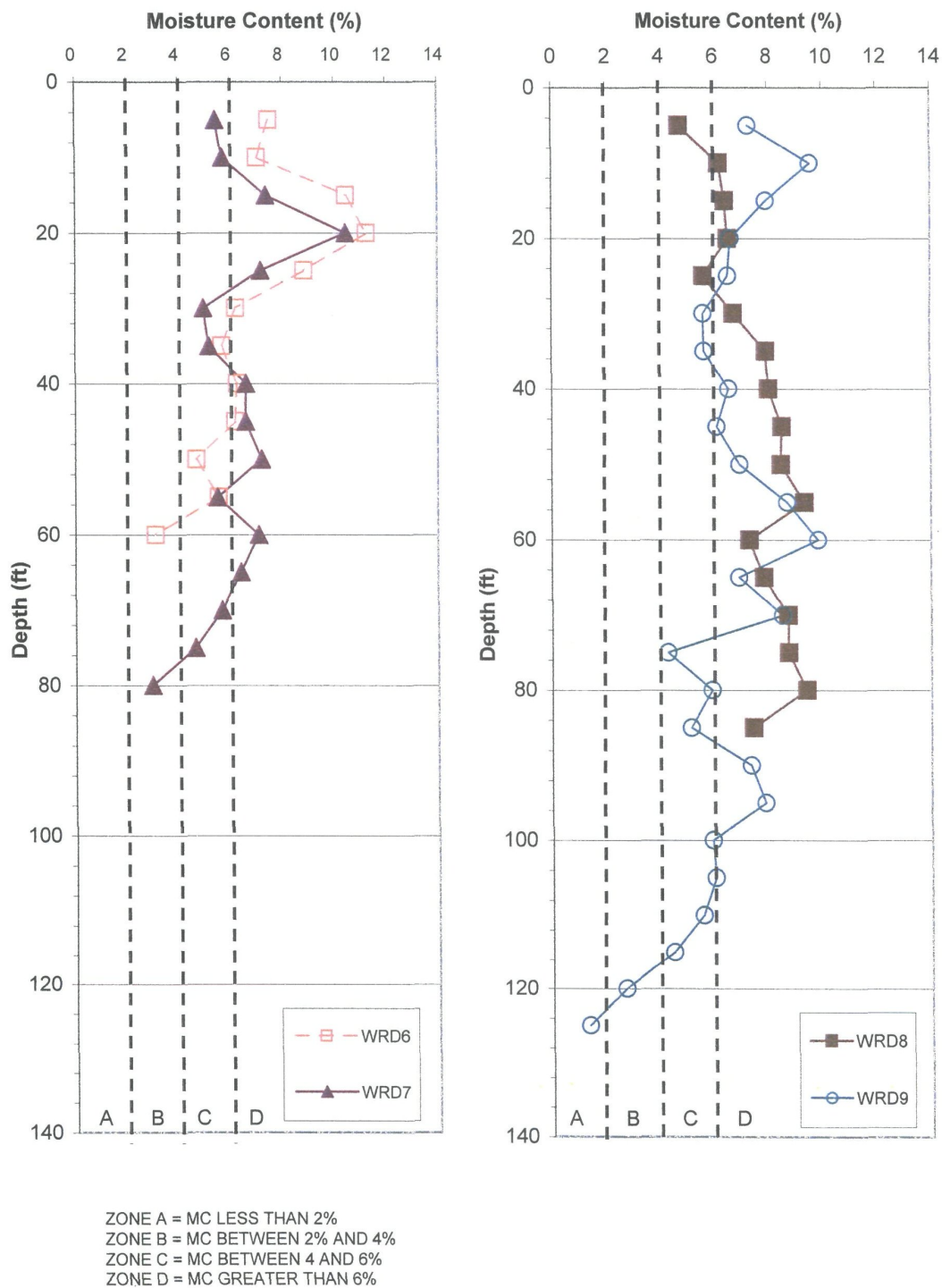
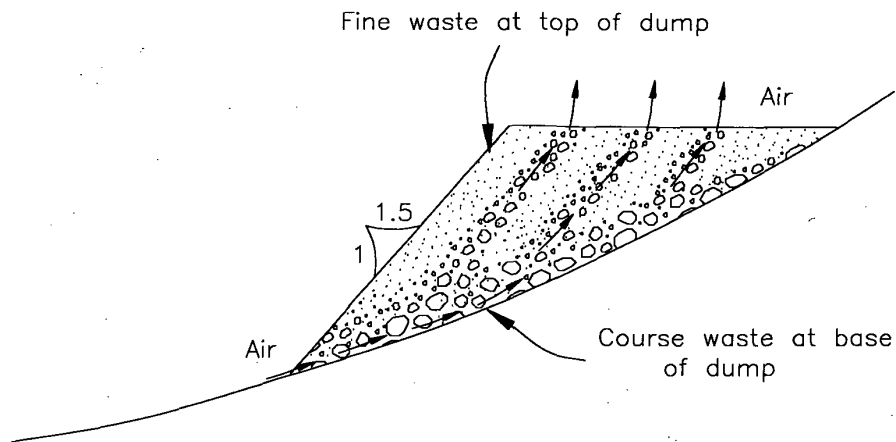
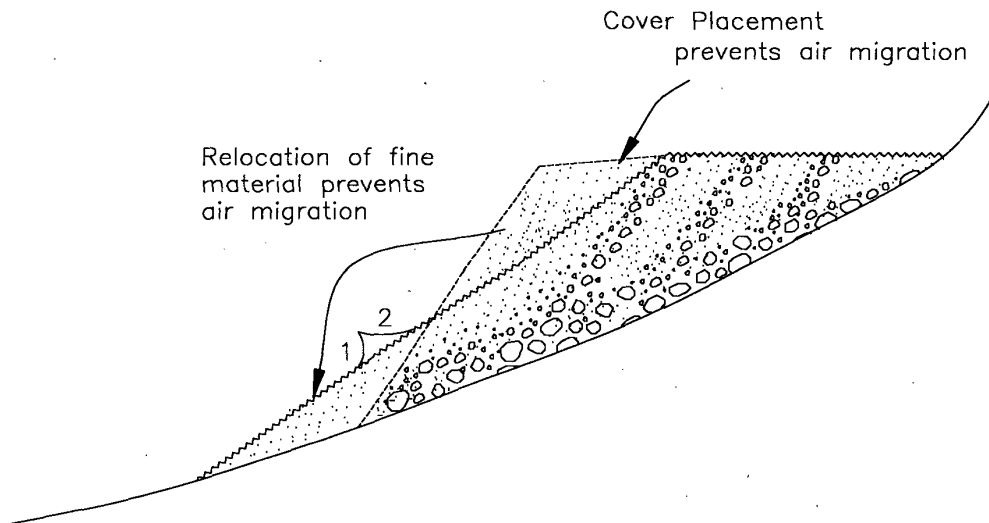


Figure 9b. Moisture Content versus Depth



a) Air Movement prior to Re-sloping



b) Effects of Re-sloping on Air Movement



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Waste Rock Pile Geochemical Characterization

**Figure No. 10**  
**Effects of Re-sloping and Covering on**  
**Air Movement through Waste Rock Dump**

PROJECT: 052007	DATE: Sept. 99	DRAWN: JG	SCALE: as shown	DWG. NO.:
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## TABLES

Table 1. Preliminary Drill Hole Log for WRD 1

Drill Hole: WRD 1		Driller: Layne Western Drilling				
Start Date 7/31/99		Equipment: AP-1000 Hammer Drill				
End Date 7/31/99		Logged By: A. Eschenbacher, SMA				
		G. Muller, SRK Consulting Inc.				
Depth From To		Lithology	Comments	Paste pH (su)	Paste Cond (µS)	Moisture Content (%)
0	5	Aplite, light grey, minor Pyrite, tan matrix	dry	8.37	634	5.1
5	10	Aplite, minor Pyrite, w/ Andestite, tan matrix	dry	7.98	1,040	1.6
10	15	Aplite, trace Pyrite, tan matrix	dry, poor recovery	7.93	1,380	4.0
15	20	Aplite, minor Andesite, light grey, tan matrix	dry	7.67	1,850	4.8
20	25	Aplite, light grey, tan matrix	dry	7.93	1,730	4.4
25	30	Andesite, >1% Pyrite, trace Molybdenum, mineralized, brown matrix	dry,color change to brown at ~27'	7.29	2,400	4.9
30	35	Andesite, >1% Pyrite, Aplite, minor Rhyolite, Fluorite, Calcite, Trace Molybdenum	dry	7.66	2,040	4.1
35	40	Andesite, trace Pyrite, minor Aplite, Calcite, dark brown matrix	dry	7.73	2,200	6.2
40	45	fresh Andesite, Calcite, dark grey to black, dark brown matrix	dry	7.68	1,750	5.0
45	50	Andesite, trace Chalcopyrite, abundant Calcite, dark grey, dark brown matrix	dry	7.84	2,340	6.2
50	55	Andesite, trace Pyrite, Calcite, dark brown matrix	dry	7.76	2,250	4.3
55	60	Andesite, porphyry, 1% Pyrite, minor calcite, dark brown matrix	dry	7.88	1,800	4.3
60	65	Andesite, abundant Calcite, dark green-grey, propylitically altered, dark brown matrix	dry	8.11	2,070	4.7
65	70	Andesite, trace Pyrite, abundant calcite, dark grey, dark brown-grey matrix		7.89	1,630	4.0
70	75	Andesite, fresh trace Pyrite, dark grey, dark grey-brown matrix	dry	7.98	1,852	3.5
75	80	Andesite, trace Pyrite, minor Calcite, dark grey-green, dark grey matrix	dry	7.46	1,650	2.5
80	85	Andesite, minor Calcite, black, minor propylitic alteration, grey matrix	dry	8.16	1,065	2.4
85	90	Andesite, trace Calcite, black, minor propylitic alteration, grey matrix	dry	8.16	1,296	1.6
90	95	Andesite, black, fresh, grey matrix	dry	8.41	836	1.3
95	100	Andesite, black, large blocks, fresh	dry	7.89	2,290	3.8

Table 2. Preliminary Drill Hole Log for WRD 2

Drill Hole: WRD 2		Driller: Layne Western Drilling				
Start Date 7/31/99		Equipment: AP-1000 Hammer Drill				
End Date 7/31/99		Logged By: A. Eschenbacher, SMA				
		G. Muller, SRK Consulting Inc.				
Depth From To		Lithology	Comments	Paste pH (su)	Paste Cond (µS)	Moisture Content (%)
0	5	mixed volcanics, mostly oxidized, yellow-brown clay rich matrix	dry	4.99	1,410	5.7
5	10	mixed volcanics, trace Pyrite, oxidized, yellow-brown clay rich matrix	dry	4.02	2,670	5.6
10	15	mixed volcanics, oxidized, yellow-brown clay rich matrix	dry	3.53	2,780	8.8
15	20	mixed volcanics, trace Pyrite, oxidized, yellow-brown clay rich matrix	dry	3.17	3,820	6.9
20	25	mixed volcanics, yellow-brown clay rich matrix	dry	3.66	4,110	8.3
25	30	mixed volcanics, yellow-brown clay rich matrix	dry	3.38	3,140	10.7
30	35	mixed volcanics, oxidized, yellow-brown clay rich matrix	dry	3.21	3,190	10.2
35	40	mixed volcanics, trace Pyrite, oxidized, yellow-brown matrix	moist	3.34	2,840	9.3
40	45	mixed volcanics, trace Pyrite, oxidized, yellow-brown clay rich matrix	moist	3.22	3,730	9.6
45	50	mixed volcanics, trace Pyrite, oxidized, yellow-brown clay rich matrix	moist	3.14	5,240	5.7
50	55	mixed volcanics trace Pyrite, yellow-brown clay rich matrix	moist	3.17	6,440	6.3
55	60	mixed volcanics, yellow-brown clay rich matrix	moist	3.28	6,370	5.6
60	65	Aplite, trace Pyrite, fresh blocks	dry	3.82	5,630	2.3
65	70	Aplite, trace Pyrite, fresh blocks	dry, poor recovery	3.66	5,390	3.5
70	75	Aplite, >1% Pyrite, fresh blocks	dry	4.15	4,220	2.0

Table 3. Preliminary Drill Hole Log for WRD 3

Drill Hole: WRD 3		Driller: Layne Western Drilling				
Start Date 7/30/99		Equipment: AP-1000 Hammer Drill				
End Date		Logged By: A. Eschenbacher, SMA				
		G. Muller, SRK Consulting Inc.				
Depth From To	Lithology		Comments	Paste pH (su)	Paste Cond ( $\mu$ S)	Moisture Content (%)
0 5	Andesite, minor Aplite, trace Pyrite, gravel in tan sand, silt size matrix		dry, split sample	6.07	2,430	2.6
5 10	Aplite, minor Andesite, fresh blocks		dry, split sample	8.02	948	0.4
10 15	Andesite, minor Aplite, trace Pyrite, large fragments		dry, split sample, poor recovery	8.16	2,280	1.3
15 20	Andesite, trace Pyrite, fresh blocks		dry, split sample, poor recovery	8.25	2,190	0.8
20 25	Andesite, trace Pyrite, fresh blocks		dry, split sample	8.12	2,370	3.5
25 30	Andesite, trace Pyrite, blocks, brown matrix		dry, split sample	7.94	2,290	4.8
30 35	Andesite, blocks		dry, split sample	7.84	2,420	4.1
35 40	Andesite, Aplite, blocks		dry, split sample	7.96	2,480	5.9
40 45	Andesite, Aplite, Rhyolite fragments, trace to minor Pyrite,		dry, split sample	7.97	2,730	4.0
45 50	Andesite, Rhyolite fragments, trace Pyrite		dry, split sample	8.27	2,150	2.3
50 55	Rhyolite, minor Pyrite, fresh hydrothermally altered volcanics		dry, split sample	7.58	2,610	2.6
55 60	Andesite, trace pyrite, minor hydrothermally altered volcanic Pyrite		dry, split sample	6.35	2,450	2.4
60 65	Andesite, minor Pyrite, hydrothermal alteration		dry, split sample	6.01	2,560	4.2
65 70	few Andesite, fragments, yellow-brown matrix		dry, split sample	4.10	3,510	5.4
70 75	Andesite, minor Pyrite, moderately hydrothermally altered, yellow-brown matrix		dry, split sample	3.90	3,630	5.1
75 80	Andesite, minor Pyrite, minor Aplite, hydrothermally altered, yellow-brown matrix		dry, split sample	3.93	3,760	4.6
80 85	Andesite, trace Pyrite, hydrothermally altered, yellow-brown matrix		dry, split sample	4.41	4,150	4.1
85 90	Andesite, minor Pyrite, minor felsic volcanic Chalcopyrite, Rhyolite, hydrothermally altered, yellow-brown matrix		dry, split sample	6.59	3,740	3.3
90 95	Andesite, trace Pyrite, minor Rhyolite, yellow-brown matrix		dry, large fragments	6.35	3,930	4.0
95 100	Andesite, Rhyolite, mixed volcanics, fresh and hydrothermally altered, yellow-brown matrix		dry, split sample	4.64	3,270	3.8
100 105	Andesite, Rhyolite mixed volcanics, yellow-brown matrix		dry, split sample	3.99	3,780	4.5
105 110	Andesite, minor Rhyolite, mixed volcanics, fresh and hydrothermally altered, yellow-brown matrix		dry, split sample	4.61	3,560	3.6
110 115	Andesite, minor Pyrite, slightly altered		dry, split sample	6.73	3,270	2.7
115 120	Andesite, minor Pyrite, slightly altered		dry, split sample	5.68	4,090	2.0

Table 4. Preliminary Drill Hole Log for WRD 4

Drill Hole: WRD 4		Driller: Layne Western Drilling				
Start Date 7/29/99		Equipment: AP-1000 Hammer Drill				
End Date		Logged By: A. Eschenbacher, SMA G. Muller, SRK Consulting Inc.				
Depth From To	Lithology	Comments	Paste pH (su)	Paste Cond (µS)	Moisture Content (%)	
0 5	mixed volcanics, hydrothermally altered, coarse gravel, tan fines	dry, whole bucket sample	4.17	1,880	5.4	
5 10	volcanics, dark brown, hydrothermally altered, mostly clay-sand sized	dry, split sample	5.11	2,930	6.3	
10 15	Andesite, Granite, angular gravel, light brown silt-clay matrix,	dry, split sample	7.40	2,400	5.5	
15 20	mixed volcanics, hydrothermally altered, dark brown fines	dry, split sample	7.19	2,720	6.7	
20 25	Aplite, Granite, Andesite, gravel	dry, split sample	7.87	2,810	4.2	
25 30	mixed volcanics, hydrothermally altered, drak brown matrix	dry, split sample	7.84	2,660	6.4	
30 35	volcanic, light grey, gravel, hydrothermally altered, tan matrix	dry, split sample	6.74	2,790	5.6	
35 40	volcanics, light grey, hydrothermally altered	dry, split sample	7.51	2,870	3.9	
40 45	mixed volcanics, grey, coarse blocks, tan matrix	dry, split sample	4.88	3,400	4.9	
45 50	volcanics, grey, coarse blocks, tan matrix	dry, split sample	4.68	3,100	4.5	
50 55	volcanics, grey, gravel <1" dia., tan matrix	slightly moist, split sample	4.85	4,160	6.6	
55 60	volcanics, grey, coarse gravel, tan matrix	slightly moist, split sample	7.78	4,170	4.9	
60 65	Andesite, dark grey, volcanic, angular, one lithology	moist, split sample	6.96	3,130	5.4	
65 70	Andesite, dark grey, volcanic, minor brown matrix, one lithology	moist, split sample	7.18	2,810	4.8	
70 75	Andesite, dark grey, volcanic, angular large fragments, slightly brown matrix	moist, more red hue than others	7.95	1,040	3.6	

**Table 5. Preliminary Drill Hole Log for WRD 5**

Drill Hole: WRD 5		Driller: Layne Western Drilling				
Start Date 8/1/99		Equipment: AP-1000 Hammer Drill				
End Date 8/1/99		Logged By: A. Eschenbacher, SMA				
		G. Muller, SRK Consulting Inc.				
Depth From To	Lithology		Comments	Paste pH (su)	Paste Cond (µS)	Moisture Content (%)
0 5	Andesite, Rhyolite, mixed volcanics, yellow-brown matrix		moist	6.18	2,590	6.8
5 10	Rhyolite, minor Andesite, brown matrix		moist	7.84	1,880	4.7
10 15	minor Aplite, mixed volcanics, yellow-brown clay rich matrix		moist	4.40	1,650	9.4
15 20	Andesite, trace Pyrite, highly altered Rhyolite, black, mixed volcanics, yellow-brown (clay-rich) matrix		moist	3.66	3,000	11.6
20 25	Andesite, minor Pyrite, highly altered Rhyolite, easily crumbled, yellow-brown clay rich matrix		moist	3.80	3,190	6.9
25 30	Andesite, trace Pyrite, minor Rhyolite, dark grey, slightly oxidized, brown matrix		dry	5.11	3,750	6.4
30 35	Andesite, Rhyolite, trace Pyrite, dark grey-brown matrix		dry	7.60	3,770	5.8
35 40	Andesite, dark grey-green, large blocks, propylitic alteration, grey matrix		dry	8.02	2,530	4.9
40 45	Andesite, trace Pyrite, Calcite, dark grey-green, propylitic alteration, grey matrix		dry	8.03	3,280	4.2
45 50	Andesite, minor Pyrite, dark green-grey, grey matrix		dry	8.34	3,430	4.3
50 55	Andesite, trace Pyrite, Calcite, dark grey-green, grey matrix		dry	7.89	3,640	4.5
55 60	Andesite, drak grey, brown matrix		dry	7.67	2,530	4.6
60 65	Andesite, Rhyolite, mixed volcanics, fresh and altered, dark brown matrix		dry	6.52	2,510	6.4
65 70	trace Pyrite, mixed volcanics, large blocks oxidized, brown matrix		dry	7.73	1,510	7.4
70 75	Andesite, trace Pyrite, Epidote, minor Rhyolite, dark grey-green, grey matrix		dry	8.11	1,050	4.9
75 80	Andesite, minor Pyrite, dark grey, large blocks, uniform, grey matrix		dry			

Table 6. Preliminary Drill Hole Log for WRD 6

Drill Hole: WRD 6		Driller: Layne Western Drilling				
Start Date 8/4/99		Equipment: AP-1000 Hammer Drill				
End Date 8/4/99		Logged By: A. Eschenbacher, SMA G. Muller, SRK Consulting Inc.				
Depth From To		Lithology	Comments	Paste pH (su)	Paste Cond (µS)	Moisture Content (%)
0	5	mixed volcanics, yellow-brown clay rich matrix	moist	3.17	3,130	7.49
5	10	mixed volcanics, dominant Tuff, trace Pyrite, grey, light brown clay rich matrix	moist	3.29	3,350	7.02
10	15	mixed volcanics, fresh, highly altered variants (bleached, oxidized), light brown clay rich matrix	moist	3.53	3,200	10.45
15	20	black Andesite, light grey Rhyolite/Tuff, mixed volcanics, light brown clay rich matrix	moist	3.62	2,960	11.25
20	25	grey Rhyolite, minor highly altered volcanics ( Rhyolite, trace Pyrite) light brown clay rich matrix	moist	3.94	2,970	8.84
25	30	grey Rhyolite, trace Pyrite, (Tuff?), grey-brown matrix	moist, drier than above	4.48	2,830	6.20
30	35	Tuff, trace Pyrite, grey, crystal, grey matrix	moist	7.37	2,860	5.66
35	40	Tuff, massive Pyrite, dark grey, very little banding, grey matrix	moist	7.50	2,430	6.24
40	45	Tuff, >1% Pyrite, Epidote, dark grey, crystal, grey matrix	slightly moist	7.71	2,850	6.16
45	50	mixed volcanics, grey Tuff, trace Pyrite, light grey Rhyolite, oxidized Rhyolite (?), grey-brown matrix	dry	7.64	3,090	4.66
50	55	mixed volcanics, dominate Tuff, >1% Pyrite, dark grey, crystal, grey-brown matrix	dry	7.50	3,410	5.52
55	60	Tuff, minor Pyrite, light grey, crystal, grey rock powder matrix	dry, competent rock-bedrock	7.81	2,980	3.08

Table 7. Preliminary Drill Hole Log for WRD 7

Drill Hole: WRD 7		Driller: Layne Western Drilling				
Start Date 8/1/99		Equipment: AP-1000 Hammer Drill				
End Date 8/2/99		Logged By: A. Eschenbacher, SMA				
		G. Muller, SRK Consulting Inc.				
Depth From	To	Lithology	Comments	Paste pH (su)	Paste Cond (µS)	Moisture Content (%)
0	5	Andesite, trace Pyrite, Aplite, yellow-brown matrix	dry	5.68	2,450	5.4
5	10	mixed volcanics, Aplite, yellow-brown matrix	dry	3.84	2,570	5.7
10	15	Aplite, mixed volcanics, yellow-brown clayey matrix	moist (raining)	3.63	2,850	7.4
15	20	mixed volcanics, Aplite, yellow-brown matrix	moist (raining)	3.09	3,140	10.4
20	25	mixed volcanics, Aplite, yellow-brown matrix	dry	3.46	3,000	7.2
25	30	mixed volcanics, dominate Andesite, brown matrix	dry	4.52	3,140	4.9
30	35	mixed volcanics, brown matrix	dry	7.18	3,100	5.2
35	40	mixed volcanics, dominant Rhyolite, rh prophyry, grey-brown matrix	dry	7.57	3,110	6.6
40	45	mixed volcanics, Aplite, grey-brown matrix	moist (lightly raining)	7.57	2,600	6.6
45	50	mixed volcanics, Aplite, brown matrix	dry	7.30	2,200	7.2
50	55	mixed volcanics, dominant grey Rhyolite, grey-brown matrix	dry	7.71	2,250	5.5
55	60	mixed volcanics, dominate Rhyolite, grey matrix	moist	7.43	2,130	7.1
60	65	grey Rhyolite, minor Andesite, grey matrix	moist	7.91	1,410	6.4
65	70	mixed volcanics, dominate Rhyolite, grey-brown matrix	moist (lightly raining)	7.63	2,400	5.6
70	75	light grey Rhyolite (partially oxidized), minor Pyrite, minor black Andesite, trace Pyrite, yellow-brown matrix	dry	4.28	2,580	4.6
75	80	Andesite, dark grey, fresh, prophyry, large blocks	dry bedrock	5.92	2,410	2.9

Table 8. Preliminary Drill Hole Log for WRD 8

Drill Hole: WRD 8		Driller: Layne Western Drilling				
Start Date 8/3/99		Equipment: AP-1000 Hammer Drill				
End Date 8/3/99		Logged By: A. Eschenbacher, SMA				
		G. Muller, SRK Consulting Inc.				
Depth From To	Lithology		Comments	Paste pH (su)	Paste Cond ( $\mu$ S)	Moisture Content (%)
0 5	Grey welded tuff, volcanic breccia, dark brown matrix		moist	3.25	2,440	4.7
5 10	Grey tuff, dark brown matrix		moist	3.47	2,480	6.2
10 15	Grey tuff, crystal rich and crystal poor varieties, dark brown clay rich matrix		moist	3.16	2,740	6.4
15 20	Dark grey tuff, trace pyrite, dark brown clay rich matrix		moist	3.23	2,730	6.5
20 25	Dark grey tuff, minor pyrite, silicified, dark grey-brown matrix		moist	6.17	2,500	5.6
25 30	Grey tuff, minor pyrite, silicified, dark grey-brown clay rich matrix		moist	3.89	2,950	6.7
30 35	Grey tuff, trace pyrite, silicified, dark brown-orange clay rich matrix		moist	3.35	2,620	7.9
35 40	Grey tuff, trace pyrite, crystal rich, brown-orange clay rich matrix		moist	3.07	2,910	8.0
40 45	Grey tuff, trace pyrite, crystal rich, brown-orange clay rich matrix		moist	3.63	2,790	8.5
45 50	Grey tuff, minor pyrite, crystal rich, grey-brown matrix		moist	3.98	2,680	8.5
50 55	Grey tuff, minor Pyrite, grey-tan clay rich matrix		moist	3.91	2,570	9.3
55 60	dark grey Tuff, trace Pyrite, crystal rich and crystal poor varieties, grey matrix		moist	4.11	2,870	7.3
60 65	dark grey Tuff, trace Pyrite, brown clay rich matrix		moist	4.02	2,760	7.8
65 70	dark grey Tuff, crystal poor, light brown clay rich matrix		moist	3.79	3,050	8.7
70 75	dark grey Tuff, trace Pyrite, light brown matrix		moist	3.95	3,100	8.7
75 80	dark grey Tuff, trace Pyrite, light brown clay rich matrix		moist, drier than above	3.93	3,380	9.4
80 85	Tuff, light grey, fresh, light brown matrix		dry	3.88	3,150	7.4

**Table 9. Preliminary Drill Hole Log for WRD 9**

Drill Hole: WRD 9		Driller: Layne Western Drilling				
Start Date 8/2/99		Equipment: AP-1000 Hammer Drill				
End Date 8/3/99		Logged By: A. Eschenbacher, SMA G. Muller, SRK Consulting Inc.				
Depth From	To	Lithology	Comments	Paste pH (su)	Paste Cond (µS)	Moisture Content (%)
0	5	Mixed volcanics, trace pyrite, oxidized clasts, light brown matrix	dry	3.10	2,780	7.3
5	10	Mixed volcanics, brown clay rich matrix	moist	3.79	1,660	9.6
10	15	Mixed volcanics, dominate andesite, black, brown clay-rich matrix	moist	3.21	3,480	7.9
15	20	black Andesite, trace Pyrite, brown clay rich matrix	moist	3.05	2,910	6.6
20	25	Black andesite, trace pyrite, minor grey rhyolite, brown matrix	moist	3.26	2,250	6.5
25	30	Tuff, dark grey, welded, brown matrix	dry, poor recovery	4.01	2,550	5.6
30	35	Mixed volcanics, andesite, trace pyrite, rhyolite, tuff, brown matrix	dry, poor recovery	3.23	2,840	5.6
35	40	Grey rhyolite, dark grey tuff, welded, light brown matrix	dry, poor recovery	3.41	2,630	6.5
40	45	Rhyolite, light grey, fresh, large blocks, light brown-grey matrix	dry	3.24	1,290	6.1
45	50	Rhyolite, light grey, fresh, large blocks, light brown-grey clay rich matrix	dry	2.89	1,720	6.9
50	55	Grey rhyolite, tuff, welded, light brown clay rich matrix	moist	3.01	3,110	8.7
55	60	Tuff, grey, welded, light brown clay rich matrix	moist	3.56	4,280	9.8
60	65	grey welded Tuff, minor oxidized Tuff with trace Pyrite, light brown clay rich matrix	dry	3.67	3,980	6.9
65	70	Tuff, >1% Pyrite, grey, crystal rich, brown clay rich matrix	moist	3.57	3,270	8.5
70	75	grey welded Tuff, Tuff breccia, boulder +/- 3' dia., minor Pyrite	dry	3.88	3,460	4.3
75	80	Reddish grey tuff, >1% pyrite, epidote, large blocks, light brown matrix	dry	4.23	3,660	5.9
80	85	Red-grey tuff, >1% pyrite, epidote, large blocks, light brown matrix	dry	6.82	3,530	5.1
85	90	Mixed volcanics, red-grey tuff, strong pyrite, oxidized and bleached crystal tuff, rhyolite (?), dark brown matrix	dry	4.59	3,960	7.3
90	95	Mixed volcanics, mostly rhyolite, red-grey, crystal rich, minor pyrite, light brown matrix	dry	3.62	3,810	7.9
95	100	Mixed volcanics, minor pyrite, light brown matrix	dry	3.42	3,330	5.9
100	105	Mixed volcanics, mostly various tuffs, fresh, oxidized, light brown clay rich matrix	dry	3.78	3,450	6.0
105	110	Mixed volcanics, light brown-grey matrix	dry	3.73	4,660	5.6
110	115	Tuff, light grey, crystal rich, boulder, light brown-grey matrix	dry	3.82	4,630	4.5
115	120	Mixed volcanics, dominate tuff, light grey, boulder, grey matrix	dry	3.90	4,940	2.7
120	125	Tuff, light grey, fresh, grey rock powder matrix	dry, bedrock	4.64	2,440	1.3

**APPENDIX A**  
**STANDARD TESTING PROCEDURES**

# **Standard Operating Procedure for Paste pH and Conductivity Testing Questa Project Field Investigation**

## **1.0 INTRODUCTION**

This Standard Operating Procedure describes the method for determining the paste pH and paste conductivity of rock and soil samples. Paste tests are used to evaluate the geochemical behavior of mine waste materials subject to weathering under field conditions. The test method that can be used to rapidly evaluate a large number of samples. Samples may be placed in test vials and prepared in advance in large batches.

Measurement of total dissolved solids content (TDS) and conductivity are analogous. Subject to equipment availability, a TDS meter may be substituted for conductivity meter.

## **2.0 MATERIALS AND EQUIPMENT**

The following materials are required for conducting paste pH and conductivity tests.

1. A pH meter with pH 4 and pH 7 calibration standards;
2. A conductivity or TDS meter with standard calibration solution(s);
3. 100 cm<sup>3</sup> plastic vials with lids (pill vials);
4. Distilled or deionized water; and
5. Vessels for rinsing pH and conductivity probes.

## **3.0 TEST PROCEDURE**

1. Calibrate pH and conductivity meters according to the manufacturer's instructions. Record the calibration data on the laboratory test data sheet(s).
2. Fill a 100 cm<sup>3</sup> vial one half full with soil or waste rock particles. The sample used for paste testing should, to the extent practical, be composed of finer material. If possible, avoid particles larger than approximately 1.25-cm (½-inch) in diameter. Place the soil or mine waste sample number on the vial with an indelible ink marker. Reseal the bag from which the paste test sample was obtained.
3. Fill each vial to the top with distilled water.
4. Place the lid on the sample vial and agitate the mixture until the sample is fully suspended.

5. Check to insure that after mixing, the water level is within  $\frac{1}{2}$  cm of the top of the vial. Add more water if required and agitate the mixture.
6. Let the vial stand for at least one minute before testing.
7. Rinse the pH and conductivity probes in distilled water
8. Place the pH and conductivity probes in the free water in each vial and record the pH, conductivity and the sample number. Rinse the probes in distilled water.
9. Where test values are observed to increase or decrease while the test probes are held in the sample, allow the sample to stand and repeat the test readings after approximately 5 minutes.
10. Rinse or replace the rinse water vessel and change the pH and conductivity probe rinse water after each 20 tests.
11. After 20 tests, place the pH and conductivity probes in the standard solutions and record readings on the laboratory data sheets. If readings on the standard solutions have drifted by more than 5 percent, recalibrate the probe, record the calibration data and retest the last 20 samples.



## Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock<sup>1</sup>

This standard is issued under the fixed designation D 2216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This test method covers the laboratory determination of the water (moisture) content of soil, rock, and similar materials by mass. For simplicity, the word "material" hereinafter also refers to either soil or rock, whichever is most applicable.

1.2 The water content of a material is defined by this standard as the ratio, expressed as a percentage, of the mass of "pore" or "free" water in a given mass of material to the mass of the solid material.

1.3 The term "solid particles" as used in geotechnical engineering is typically assumed to mean naturally occurring mineral particles of soil and rock that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement, and the like) may require special treatment or a qualified definition of water content. In addition, some organic materials may be decomposed by oven drying at the standard drying temperature for this method (110°C). Materials containing gypsum (calcium sulfate dihydrate or other compounds having significant amounts of hydrated water) may present a special problem as this material slowly dehydrates at the standard drying temperature (110°C) and at very low relative humidities, forming a compound (calcium sulfate hemihydrate) which is not normally present in natural materials except in some desert soils. In order to reduce the degree of dehydration of gypsum in those materials containing gypsum, or to reduce decomposition in highly organic soils, it may be desirable to dry these materials at 60°C or in a desiccator at room temperature. Thus, when a drying temperature is used which is different from the standard drying temperature as defined by this test method, the resulting water content may be different from standard water content determined at the standard drying temperature.

NOTE 1—Test Methods D 2974 provides an alternate procedure for determining water content of peat materials.

1.4 Materials containing water with substantial amounts of soluble solids (such as salt in the case of marine sediments) when tested by this method will give a mass of solids which includes the previously soluble solids. These materials require special treatment to remove or account for the presence of precipitated solids in the dry mass of the

specimen, or a qualified definition of water content must be used.

1.5 This test method requires several hours for proper drying of the water content specimen. Test Method D 4643 provides for drying of the test specimen in a microwave oven which is a shorter process.

1.6 This standard requires the drying of material in an oven at high temperatures. If the material being dried is contaminated with certain chemicals, health and safety hazards can exist. Therefore, this standard should not be used in determining the water content of contaminated soils unless adequate health and safety precautions are taken.

1.7 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:

- D 653 Terminology Relating to Soil, Rock, and Contained Fluids<sup>2</sup>
- D 2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils<sup>2</sup>
- D 4220 Practice for Preserving and Transporting Soil Samples<sup>2</sup>
- D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils<sup>2</sup>
- D 4643 Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method<sup>2</sup>
- D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing<sup>2</sup>
- E 145 Specification for Gravity-Convection And Forced-Ventilation Ovens<sup>3</sup>

### 3. Terminology

3.1 Refer to Terminology D 653 for standard definitions of terms.

#### 3.2 Description of Term Specific to This Standard:

3.2.1 *water content* (of a material)—the ratio of the mass of water contained in the pore spaces of soil or rock material to the solid mass of particles in that material, expressed as a percentage.

<sup>1</sup> This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved June 15, 1992. Published August 1992. Originally published as D 2216 - 63 T. Last previous edition D 2216 - 90<sup>1</sup>.

<sup>2</sup> Annual Book of ASTM Standards, Vol 04.08.

<sup>3</sup> Annual Book of ASTM Standards, Vol 14.02.

#### 4. Summary of Test Method

4.1 A test specimen is dried in an oven to a constant mass. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

#### 5. Significance and Use

5.1 For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and its properties.

5.2 The water content of a material is used in expressing the phase relationships of air, water, and solids in a given volume of material.

5.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limits as determined by Test Method D 4318, is used to express its relative consistency or liquidity index.

#### 6. Apparatus

6.1 *Drying Oven*, thermostatically-controlled, preferably of the forced-draft type, meeting the requirements of Specification E 145 and capable of maintaining a uniform temperature of  $110 \pm 5^\circ\text{C}$  throughout the drying chamber.

6.2 *Balances*—All balances must meet the requirements of Specification D 4753 and this Section. A Class GP1 balance of 0.01g readability is required for specimens having a mass of up to 200 g (excluding mass of specimen container) and a Class GP2 balance of 0.1g readability is required for specimens having a mass over 200 g.

6.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, exposure to materials of varying pH, and cleaning. Containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used. One container is needed for each water content determination.

NOTE 2—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial mass determination and to prevent absorption of moisture from the atmosphere following drying and before final mass determination.

6.4 *Desiccator*—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium phosphate. It is preferable to use a desiccant which changes color to indicate it needs reconstitution. See Section 10.5.

NOTE 3—Anhydrous calcium sulfate is sold under the trade name Drierite.

6.5 *Container Handling Apparatus*, gloves, tongs, or suitable holder for moving and handling hot containers after drying.

6.6 *Miscellaneous*, knives, spatulas, scoops, quartering cloth, sample splitters, etc., as required.

#### 7. Samples

7.1 Samples shall be preserved and transported in accordance with Practice 4220 Groups B, C, or D soils. Keep the samples that are stored prior to testing in noncorrodible airtight containers at a temperature between approximately 3 and  $30^\circ\text{C}$  and in an area that prevents direct contact with

sunlight. Disturbed samples in jars or other containers shall be stored in such a way as to prevent or minimize moisture condensation on the insides of the containers.

7.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corrodible containers (such as thin-walled steel tubes, paint cans, etc.) or plastic sample bags are used.

#### 8. Test Specimen

8.1 For water contents being determined in conjunction with another ASTM method, the specimen mass requirement stated in that method shall be used if one is provided. If no minimum specimen mass is provided in that method then the values given before shall apply.

8.2 The minimum mass of moist material selected to be representative of the total sample, if the total sample is not tested by this method, shall be in accordance with the following:

Maximum particle size (100 % passing)	Standard Sieve Size	Recommended minimum mass of moist test specimen for water content reported to $\pm 0.1$ %	Recommended minimum mass of moist test specimen for water content reported to $\pm 1$ %
2 mm or less	No. 10	20 g	20 g <sup>a</sup>
4.75 mm	No. 4	100 g	20 g <sup>a</sup>
9.5 mm	3/8-in.	500 g	50 g
19.0 mm	3/4-in.	2.5 kg	250 g
37.5 mm	1 1/2 in.	10 kg	1 kg
75.0 mm	3-in.	50 kg	5 kg

NOTE—<sup>a</sup>To be representative not less than 20 g shall be used.

8.2.1 If the total sample is used it does not have to meet the minimum mass requirements provided in the table above. The report shall indicate that the entire sample was used.

8.3 Using a test specimen smaller than the minimum indicated in 8.2 requires discretion, though it may be adequate for the purposes of the test. Any specimen used not meeting these requirements shall be noted in the report of results.

8.4 When working with a small (less than 200g) specimen containing a relatively large gravel particle, it is appropriate not to include this particle in the test specimen. However, any discarded material shall be described and noted in the report of the results.

8.5 For those samples consisting entirely of intact rock, the minimum specimen mass shall be 500 g. Representative portions of the sample may be broken into smaller particles, depending on the sample's size, the container and balance being used and to facilitate drying to constant mass, see Section 10.4.

#### 9. Test Specimen Selection

9.1 When the test specimen is a portion of a larger amount of material, the specimen must be selected to be representative of the water condition of the entire amount of material. The manner in which the test specimen is selected depends on the purpose and application of the test, type of material being tested, the water condition, and the type of sample (from another test, bag, block, and the likes.)

9.2 For disturbed samples such as trimmings, bag samples, and the like, obtain the test specimen by one of the

following methods (listed in order of preference):

9.2.1 If the material is such that it can be manipulated and handled without significant moisture loss, the material should be mixed and then reduced to the required size by quartering or splitting.

9.2.2 If the material is such that it cannot be thoroughly mixed and/or split, form a stockpile of the material, mixing as much as possible. Take at least five portions of material at random locations using a sampling tube, shovel, scoop, trowel, or similar device appropriate to the maximum particle size present in the material. Combine all the portions for the test specimen.

9.2.3 If the material or conditions are such that a stockpile cannot be formed, take as many portions of the material as possible at random locations that will best represent the moisture condition. Combine all the portions for the test specimen.

9.3 Intact samples such as block, tube, split barrel, and the like, obtain the test specimen by one of the following methods depending on the purpose and potential use of the sample.

9.3.1 Carefully trim at least 3 mm of material from the outer surface of the sample to see if material is layered and to remove material that is drier or wetter than the main portion of the sample. Then carefully trim at least 5 mm, or a thickness equal to the maximum particle size present, from the entire exposed surface or from the interval being tested.

9.3.2 Slice the sample in half. If material is layered see Section 9.3.3. Then carefully trim at least 5 mm, or a thickness equal to the maximum particle size present, from the exposed surface of one half, or from the interval being tested. Avoid any material on the edges that may be wetter or drier than the main portion of the sample.

NOTE 4—Migration of moisture in some cohesionless soils may require that the full section be sampled.

9.3.3 If a layered material (or more than one material type is encountered), select an average specimen, or individual specimens, or both. Specimens must be properly identified as to location, or what they represent, and appropriate remarks entered on data sheets.

## 10. Procedure

10.1 Determine and record the mass of the clean and dry specimen container (and its lid, if used).

10.2 Select representative test specimens in accordance with Section 9.

10.3 Place the moist test specimen in the container and, if used, set the lid securely in position. Determine the mass of the container and moist material using a balance (See 6.2) selected on the basis of the specimen mass. Record this value.

NOTE 5—To prevent mixing of specimens and yielding of incorrect results, all containers, and lids if used, should be numbered and the container numbers shall be recorded on the laboratory data sheets. The lid numbers should match the container numbers to eliminate confusion.

NOTE 6—To assist in the oven-drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

10.4 Remove the lid (if used) and place the container with moist material in the drying oven. Dry the material to a

constant mass. Maintain the drying oven at  $110 \pm 5^\circ\text{C}$  unless otherwise specified (see 1.3). The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good judgment, and experience with the materials being tested and the apparatus being used.

NOTE 7—In most cases, drying a test specimen overnight (about to 16 h) is sufficient. In cases where there is doubt concerning the adequacy of drying, drying should be continued until the change in mass after two successive periods (greater than 1 h) of drying is an insignificant amount (less than about 0.1 %). Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

NOTE 8—Since some dry materials may absorb moisture from moist specimens, dried specimens should be removed before placing moist specimens in the same oven. However, this would not be applicable to the previously dried specimens will remain in the drying oven for an additional time period of about 16 h.

10.5 After the material has dried to constant mass remove the container from the oven (and replace the lid if used). Allow the material and container to cool to room temperature or until the container can be handled comfortably without bare hands and the operation of the balance will not be affected by convection currents and/or its being heated. Determine the mass of the container and oven-dried material using the same balance as used in 10.3. Record this value. Tight fitting lids shall be used if it appears that the specimen is absorbing moisture from the air prior to determination of its dry mass.

NOTE 9—Cooling in a desiccator is acceptable in place of tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling especially for containers without tight fitting lids.

## 11. Calculation

11.1 Calculate the water content of the material as follows:

$$w = [(M_{cws} - M_{cs}) / (M_{cs} - M_c)] \times 100 = \frac{M_w}{M_s} \times 100$$

where:

$w$  = water content, %,   
 $M_{cws}$  = mass of container and wet specimen, g,   
 $M_{cs}$  = mass of container and oven dry specimen, g,   
 $M_c$  = mass of container, g,   
 $M_w$  = mass of water ( $M_w = M_{cws} - M_{cds}$ ), g, and   
 $M_s$  = mass of solid particles ( $M_s = M_{cds} - M_c$ ), g.

## 12. Report

12.1 The report (data sheet) shall include the following:   
 12.1.1 Identification of the sample (material) being tested such as boring number, sample number, test number, container number etc.

12.1.2 Water content of the specimen to the nearest 1 % or 0.1 %, as appropriate based on the minimum sample used. If this method is used in concert with another method the water content of the specimen should be reported to the value required by the test method for which the water content is being determined.

12.1.3 Indicate if test specimen had a mass less than the minimum indicated in 8.2.

**D14** Indicate if test specimen contained more than one material type (layered, etc.).

**D15** Indicate the method of drying if different from drying at  $110 \pm 5^\circ\text{C}$ .

**D16** Indicate if any material (size and amount) was added from the test specimen.

#### **13 Precision and Bias**

**13.1 Statement on Bias**—There is no accepted reference method for this test method; therefore, bias cannot be determined.

#### **13.2 Statements on Precision:**

**13.2.1 Single-Operator Precision**—The single-operator coefficient of variation has been found to be 2.7 percent.

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Therefore, results of two properly conducted tests by the same operator with the same equipment should not be considered suspect unless they differ by more than 7.8 percent of their mean.

**13.2.2 Multilaboratory Precision**—The multilaboratory coefficient of variation has been found to be 5.0 percent. Therefore, results of two properly conducted tests by different operators using different equipment should not be considered suspect unless they differ by more than 14.0 percent of their mean.

#### **14. Keywords**

14.1 consistency; index property; laboratory; moisture analysis; moisture content; soil aggregate; water content